PLATE I

THE MOON

Astron
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SUNS & WORLDS

AN INTRODUCTION TO ASTRONOMY

BY
W. H. STEAVENSON

THE HOW-&-WHY SERIES
EDITED BY
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SUNS AND WORLDS

CHAPTER I

THE EARTH AS A VIEW-POINT

ASTRONOMY is, in itself, one of the simplest of all the sciences. It is rather the conditions under which it has to be studied that give rise to the difficulties encountered by the investigator and the student.

Of course, the outstanding handicap of the astronomer is the intangibility of the heavenly bodies. No other scientific worker is quite so fettered in his attempts to probe the secrets of Nature. With the sole exception of meteorites, nothing which we see in the sky can ever be actually handled. The rays of light are the only connecting link between Man and the Stars, and the astronomer can only study these rays with his eye or with some artificial substitute therefor. Under these conditions, the only information obtainable about a celestial object is such as can be deduced from its position, its motion, its apparent shape and surface-markings, and the amount and character of its light.

This restriction is serious enough, but what makes it very much worse is the fact that we cannot even choose our view-point. And not only

does this circumstance stand in the way of all research, but it also adds greatly to the difficulties of those who are approaching the subject for the first time, and who wish to obtain a clear idea of what is going on around them in the Universe. Astronomy would be a much more simple affair if we had the power to view various parts of Space from many different angles successively, for we should then have the same sort of advantage as an aerial survey would give us in an attempt to define the outlines of a forest or to follow the manœuvrings of a battle fleet. As it is, all our observations have to be made from the surface of a body that is globular in shape, about 8000 miles in diameter, and in constant and rather complicated motion. Each of these three factors—shape, size, and movement—has its own special effects on our view of outside objects. It will be convenient if we consider the three separately, always remembering that the effects are produced constantly and simultaneously.

The principal effect of the rotundity of the Earth is that, at any one moment, no two places have quite the same view of the sky. Each observer has, spread over him, a star-studded canopy having the appearance of a hemispherical dome, seen from the inside. The other half of the star-sphere is, of course, hidden from him by the body of the Earth, which all around forms the lower boundary of the dome, or, as we call it, the 'horizon'. If we make a simple diagram, showing the Earth as a small circle surrounded at some distance by a much larger circle, the star-sphere, it will be clear that

for each place on the Earth a different point in the heavens will be overhead, and it follows also that the horizon of every such place will seem to touch the sky at correspondingly different points. Naturally, for places that are comparatively close to one another, the differences are slight. Every circle is divided into 360 degrees, and it is obvious that if an observer moves $\frac{1}{360}$ of the way round the world, his overhead point, or 'zenith', will move just one degree, or twice the apparent diameter of the Moon, among the stars. Of course, he himself has also moved through an angle of one degree as measured from the centre of the Earth. The distance he would have to travel along the Earth's surface in order to cover this angle would be about 69 miles. It is very easy to see that to go completely round the world he would have to travel 360 times this distance, which makes the circumference of the Earth nearly 25,000 miles, corresponding to a diameter of just under 8000 miles. This is, in fact, the method whereby the size of the Earth has actually been determined.

The effect which the Earth's size has on our observations of the heavens can best be understood by viewing the objects in a room, first with one eye and then with the other, the head being held all the time in the same position. When this is done it will be seen that near objects appear to move to left or right against the background formed by the far wall; and the nearer an object is to the observer the greater will be its apparent shift. The distance between the two eyes, about $2\frac{1}{2}$ inches, makes it necessary for each to look in

a slightly different direction in order to see any near object, and the effort which we half unconsciously make in turning each eye by the required amount is the means whereby we normally estimate the distance of such an object. Now, if instead of two eyes a few inches apart you picture two observers, one on each side of the Earth, you have the same state of things on a larger scale. Our background, instead of being the wall of the room, is the starry sky, and the 'near' objects are the Sun, Moon, and planets, which our two observers see in slightly different directions because they are 8000 miles apart. Actually even this great separation makes no difference that is large enough for the naked eye to detect, except in the case of the Moon, but the change can be readily measured with a powerful telescope, and we shall see in the next chapter how very important such measures have proved.

I think it will be clear that neither the shape nor the size of the Earth can of itself have any effect on the appearance of the sky for an observer who remains in one position. But the fact is that no such person exists, for every place of observation must inevitably share in the motions of the Earth itself, and it is these motions which bring about the most striking effects to be seen in the heavens. We must understand such movements and make due allowance for the results of them before we can get a clear idea of what is taking place outside the Earth.

It is quite hard to realize that such a seemingly firm and massive body as our world can be con-

stantly on the move; in fact the ancients refused for a very long time to believe in such a sensational doctrine. The perfect smoothness of the movement is the real cause of the difficulty. Nearly all our experience teaches us to associate motion with a certain amount of noise and vibration. Besides this there is generally a rush of air or water past our bodies when we are travelling rapidly on land or sea, and these things help to remind us that we are not at rest. But there are occasions when these outward signs of movement are almost absent, as when we ascend a building in a very smooth-running lift, or are towed slowly from the quay-side in a large liner. At such times it is almost impossible to tell by our feelings and sight alone that it is we that are in motion and not our surroundings. So it is with all the movements of the Earth, which are so smooth and uniform as almost to deceive us into thinking we are at rest. But you must accept my assurance that such movements are actual facts which can definitely be proved.

The motion which has the quickest and most obvious effect is the rotation of our globe on its axis in 24 hours. As we cannot actually feel this motion the result is that the whole star-sphere seems to be revolving round *us*, every object in the sky being affected in the same way. Every observer is being carried round constantly from West to East, so that the Sun, Moon, and stars appear to be moving in the opposite direction—that is, from East to West. The alternation of day and night results, as everyone knows, from this motion alone, but not so many people realize that

the stars and planets rise and set in the same way. You can convince yourself of this on any clear night by watching some star when it is not far from the Eastern or Western horizon. In a very few minutes you will be able to see that it has moved, especially if you stand so that it appears nearly in a line with some tree-top or chimney-stack. You could go on watching all night, and then you would find that the stars which were just rising in the East at sunset passed across the Southern sky, being at their highest about midnight, and set in the West about dawn. The same procession of stars is going on in the hours of daylight, and it is only the sunlight, illuminating the air through which we have to observe, which prevents our seeing the feeble gleams of these bodies. The brighter ones can, however, be clearly seen with a telescope even at midday.

When any globe, such as the Earth, is rotating, there must always be two points upon it which do not move. These are the two ends of the axis, or the North and South Poles. The further a place is from either Pole the larger is the distance through which it travels in the course of a day, and evidently a place on the Equator traces out the largest circle of all. Now the turning of the Earth makes the same thing appear to happen on the star-sphere which lies all around it. The points in the sky towards which the Earth's axis points seem to remain stationary, and the further a star happens to be from either of these points (which are called the Celestial Poles) the larger is the circle which it describes each day. Half-way between the celes-

tial poles lies the celestial equator, the largest circle of all. You can easily see that it must always be overhead for an observer on the Earth's Equator, just as the celestial poles are overhead for observers at the Earth's poles. If you live in England, which is nearly half-way from the North Pole towards the Equator, the North celestial pole will obviously not be overhead but will be seen nearly half-way down towards the Northern horizon. Round this point in the sky, which happens by chance to be marked quite closely by a conspicuous star (called the Pole Star), the heavens appear to be turning. Those stars which lie near to it seem to move in comparatively small circles, and their motion is therefore slow, since every part of the sky, however far from the apparent centre of rotation, has the same time—24 hours—in which to complete its circuit. Further from the celestial pole the stars sweep out wider circles, but clearly those which are no further from it than the Northern horizon will remain perpetually in view. On the other hand, any star that is further than this from the pole will disappear below the horizon for a longer or shorter period, according to the size of the circle which its position on the star-sphere makes it trace out. Stars far North of the celestial equator either do not set at all or remain invisible for only a small part of the 24 hours. Those on the equator are 12 hours above and 12 hours below the horizon, while those further South are longer invisible than visible. Finally, there is a circular area round the South celestial pole in which the stars remain constantly invisible to us. If we were to travel South,

this area of invisible stars would grow smaller and smaller. At the same time the North celestial pole would gradually sink towards the Northern horizon so that the area of perpetually visible stars would also grow smaller. When we reached the Earth's Equator we should find that both these areas (of perpetually invisible and perpetually visible stars) had shrunk to nothing. The two celestial poles would both lie on the horizon, in opposite directions, and every star in the sky would, at some time or other, be visible to us. For those who live far South of the Equator, in such places as South Africa or Australia, the conditions are the reverse of what they are in England. That is to say, the area of permanently visible stars is that which surrounds the South celestial pole, while it is the ones round our Northern pole which are for ever invisible.

If rotation were the only motion of the Earth, we should always see the same stars every night, and at the same hours, while the ones that were nearly behind the Sun would remain invisible to the naked eye. But we are all the time revolving round the Sun once in a year, which makes that body appear to move gradually from one part of its starry background to another. So, by waiting for a few weeks, we can see in a dark sky stars which were previously so nearly in the same direction as the Sun that they were only up in daylight hours. In six months' time these same stars would be in the opposite part of the sky to that occupied by the Sun, and would be due South at midnight instead of at noon. Later the Sun would approach

them again, and towards the end of a year they would become lost to view in the Western twilight just after sunset. Thus the aspect of the night sky is slowly changing throughout the year, and the stars which you would see on a summer evening are quite a different set from those which would be visible on a winter night.

The shape of the Earth's path is nearly but not quite circular, and the Sun is not exactly in the centre of it. We are a very little nearer to our source of light and heat in January than we are in July, but the difference is hardly large enough to have a noticeable effect on the climate of the Earth as a whole. The seasonal changes which we actually experience are due to a very different cause. If the Earth moved round the Sun with its axis upright, you can see, from a simple diagram, that the Sun would always be overhead at some point along the Equator. Here his rays would pour down vertically and therefore give the greatest amount of heat. At either pole he would be 90 degrees from the zenith and therefore perpetually on the horizon, where he would exercise very little heating power. In intermediate latitudes he would be somewhere between these two extreme positions, and the temperature would vary accordingly. So, for any one place, the temperature would be practically constant throughout the year, and the day and night would everywhere be of equal length—each twelve hours long. But this rather monotonous state of things is entirely upset by the fact that the axis of rotation is tilted 23½ degrees, or just over a quarter of a right-angle, from the position we have

just been considering. Except for a very slow change, which I shall mention presently, the axis remains pointed towards the same part of the star-sphere, and the result is that during one-half of the year the Northern parts of the Earth are turned more or less towards the Sun, while during the second half it is the Southern parts that are so directed (see Fig. 1).

The moment at which the North Pole of the Earth is leaning most nearly towards the Sun is known as the 'Summer Solstice' of the Northern Hemisphere, and occurs on June 21 or 22. The Sun must then be overhead at places which are 23½ degrees North of the Earth's Equator, and at the same time it must appear to be 23½ degrees North of the celestial equator, as you may see from the diagram. Places within 23½ degrees of the North Pole will have no night at all (hence the so-called 'midnight sun' seen in the arctic regions), while those a little further South will have a very long day and a very short night. In England, for instance, the day at midsummer is more than twice as long as the night. But as we approach the Equator the difference becomes less, and actually on that line the day and night are of equal length. Three months later neither of the Earth's poles is turned towards the Sun, which is once more overhead at the Equator. The days and nights are then equal all over the Earth, and this condition of things is consequently known as the 'Equinox' —in this case the Autumn Equinox of the Northern Hemisphere. Again, three months later, the South Pole is the one turned towards the Sun,

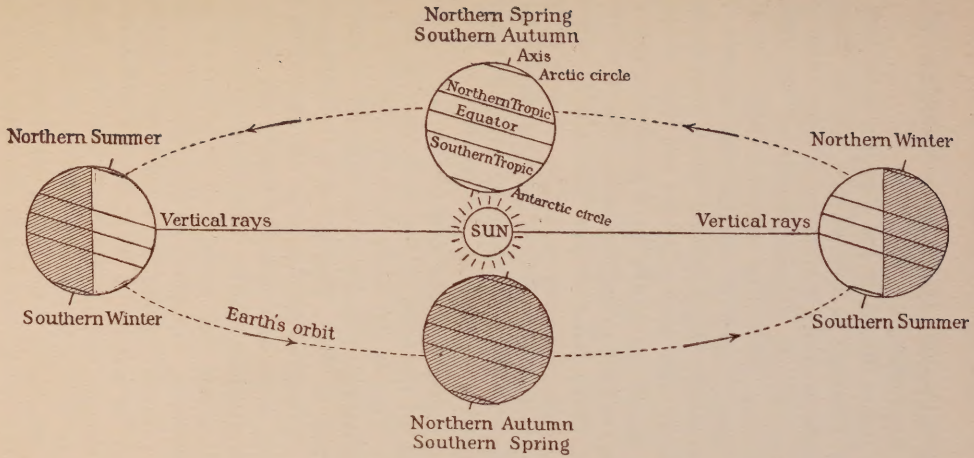


FIG. 1.—THE SEASONS

and the Summer Solstice of the Southern Hemisphere has arrived.

For places North of the Equator it is now the Winter Solstice, or mid-winter, and in England the nights are more than twice as long as the days. The Sun is $23\frac{1}{2}$ degrees South of the celestial equator, and from this moment begins to move North again, until it reaches the equator once more at the Spring Equinox, three months later.

Between the two solstices the Sun evidently moves North or South by a total amount of 47 degrees (twice $23\frac{1}{2}$ degrees) and, except within the tropics, there must be just this much difference in its height in the sky at midday. It is this change of height, and therefore of heating power, that is the cause of all those alternations of temperature that are familiar to us as the Seasons.

I have said that the axis of the Earth remains pointed all the time to the same part of the star-sphere. This is not quite strictly true, for a slow and continuous change in its direction is going on from year to year. The Earth is behaving rather like a top that is coming near the end of its spin. The tilt of its axis remains nearly the same, but there is a reeling motion which causes it to describe a circle about the vertical in a period of nearly 26,000 years. The effect of this change is that the Sun's position among the stars at each successive equinox or solstice is very slightly different each year, though the change is so slow that it would be some centuries before the effects would become really noticeable to the naked eye. But if you could live 1000 years you would find that the celestial

pole had moved a considerable distance from the present 'Pole-star'; while in 13,000 years it would be as much as 47 degrees away from it, and the stars which are now behind the Sun at midsummer would at that season be visible at midnight.

All these motions of the Earth combine to make Astronomy appear rather a complicated and difficult science; but, taken separately, they are quite simple, and, once you have grasped them and their effects, very little that is at all puzzling remains to be learnt. But, before leaving the subject, I must mention one very important use which we make of these motions, and that is the reckoning of Time.

The rotation of the Earth is, for all practical purposes, absolutely smooth and uniform, so that it makes an ideal timekeeper. We can therefore regard it as a giant clock, on which any fixed telescope will act as the hour-hand, with the star-sphere as the clock-face. As the Earth rotates, the hour-hand will point to one star after another, coming round to the same star always at regular intervals. This taking of time by the stars is the simplest of all methods of marking the progress of the hours, and astronomers always use it. The great objection to its general employment is that the Sun, by which we have to regulate all our activities, does not remain stationary among the stars. In fact, as we have just seen, the motion of the Earth is causing it constantly to change its apparent position towards the left, as seen from the Northern hemisphere. The amount of this motion is such that it appears to lag behind the general motion of the

star-sphere by about four minutes of time each day. So, if we were taking our time by the stars, we should be nearly an hour out by the Sun in the course of a fortnight, and as much as twelve hours out in six months. The obvious solution would seem to be to ignore the stars and to take our time by the Sun, making our day four minutes longer. This is what the ancients did, and it served their rough purposes. But with the coming of clocks it ceased to be good enough, and for this reason. The Sun's motion round the heavens is not uniform, like the movement of a clock. As we have seen, a great portion of its time is spent in moving Northwards or Southwards instead of simply from West to East. In addition to this, it appears to move more quickly in January than in July, because the Earth, being nearer to the Sun, is moving faster then. Consequently our days, judged by the Sun alone, are not of exactly equal length, and there are actually very few days in the year on which the time taken from the Sun would agree with that shown by a good clock. To get over the difficulty astronomers have invented an entirely imaginary Sun, a sort of ideal body which *does* move regularly round the heavens, giving equal length to each day. The motion of this body is equal to the average, or mean, motion of the real Sun, and the time taken from it is consequently called Mean Time. This is the time shown by all our clocks and used for all the purposes of our daily life.

CHAPTER II

THE SUN'S FAMILY

THE great majority of the objects seen in the night sky remain apparently fixed on the star-sphere and can be recognized year after year in the same relative positions, though of course they all seem to move completely round the Earth once a day. But here and there a few star-like objects will be found to have an independent motion of their own, which carries them round the heavens in different periods of time. These are the planets, which, though so much like stars in appearance, are really bodies of a very different kind. Five of them are readily visible to the naked eye, and these are all bright objects, two of them being always more conspicuous than the most brilliant of the so-called 'fixed' stars. Yet they are actually dark globes like the Earth, and only shine to us because they are lit up by the Sun, round which, like us, they are revolving, each in its separate path or orbit. Being such prominent objects they have naturally been observed from the earliest times, so that there is no record of their discovery. It was, however, a long time before the true nature of their motions was understood.

The astronomers of antiquity were obsessed with the idea that the Earth was stationary in Space, and, although some of the more astute Greek philosophers guessed, over two thousand years ago, that the Earth with all the other planets was really in revolution round the Sun, the theory

gained little ground until it was revived by Copernicus in the Sixteenth Century. From that time onwards the difficulties began to disappear, for the puzzling to-and-fro movements of the planets were seen to have a simple explanation as merely apparent effects due to the combination of their own motion with that of the Earth round the Sun.

Even then the motions were not entirely accounted for, chiefly because it had been assumed that the planets moved in perfectly circular paths. But in the Seventeenth Century, Kepler, making use of the accurate observations of Tycho Brahe, smoothed away this last real difficulty by showing that the orbits were not circles but ellipses, with the Sun not quite in the centre of each. He further showed that the motion of a planet moving in such a path varied with its distance from the Sun, and he was able to deduce a set of laws whereby the position of a planet in its orbit at any moment could be predicted.

The true explanation of Kepler's laws of planetary motion was supplied many years later by Sir Isaac Newton, who showed that they were the natural result of the force of gravitation, whereby all bodies attracted one another in a perfectly regular and predictable manner, depending solely on their masses and distances apart.

Kepler had carefully compared the planetary orbits with one another, and one of the laws which he deduced enabled him to find the exact relation between their lengths. That is to say, he was able to construct a diagram on which the distance of each planet from the Sun could be laid down in

true proportion. What he could not do was to give the *actual* distances in miles. In fact his diagram, though otherwise complete, lacked the necessary scale which one finds in the corner of every map or plan. The determination of this scale has always been regarded as one of the most important problems of Astronomy, because it gives us the radius of the Earth's orbit, which is the standard used for measuring the distances of the stars.

I have already mentioned the way in which the distance of an inaccessible object can be measured by noticing how it seems to change its direction in Space when looked at from each end of a line of known length. This method of measurement, which is used by all land surveyors, is known as 'triangulation', because what we are really measuring is the dimensions of a triangle from a knowledge of the length of its base and the size of the angles at either end of the same. If the object whose distance we are measuring is very far away the triangle will be a very long one, and that means that the two sides will be only slightly inclined to one another, and a very small error in measuring that inclination will make a great deal of difference in the distance deduced from our observations. But when the object is nearer, or the base longer, the inclination of the two sides of the triangle is much greater, and errors of observation have a smaller effect. This is of importance when we come to measure the distances of the Sun and planets. So long as we can find the actual separation in miles between *any two* of these bodies, our purpose will clearly have been accomplished, since all the

other distances can be deduced from it by means of Kepler's diagram. Therefore we naturally choose to measure the distance of one that passes as near as possible to the Earth, so that our result may be the more accurate.

We are, unfortunately, limited as to the length of our base-line, which cannot be greater than the diameter of the Earth, or rather less than 8000 miles; and in practice we have to be satisfied with something even smaller than that. Our observations consist in noting the direction in which the neighbouring planet lies against the background of stars as seen from two widely separated places on the Earth. Alternatively the observations may be made from one and the same place, but at an interval of several hours, during which the rotation of the Earth will have carried the observer through a known number of miles.

So great is the distance of even the nearest planet that the naked eye could scarcely distinguish any difference in its direction, though the observations were made several thousand miles apart. But the invention of the telescope made such delicate measures possible, and astronomers soon took advantage of the new instrument. The result has been that, during the past two and a half centuries, many attempts of increasing accuracy have been made to measure the distances of the nearest planets, and we can now claim to know the scale of Kepler's diagram to within about a thousandth part of its true value. When we come to apply this scale to the diagram we find that the distance of the Earth from the Sun is about 93,000,000 miles, and this

is the only planetary distance which it is at all important to remember, for reasons which I have explained. The others need not be thought of in miles but in the proportion which they bear to this celestial standard of length, which is called the 'astronomical unit'. Bearing this in mind, we can now proceed to a rough survey of the Sun's planetary family, more generally called the Solar System.

The nearest planet to the Sun is Mercury, whose average distance from his primary is just over one-third that of the Earth. I say 'average' because Mercury's path is less circular than that of any other of the bright planets, and the Sun is further from its centre. Mercury takes about three months to complete the circuit of his orbit, so this is the length of his 'year'. The shortness of this period is due not only to the smaller distance which he has to cover, but also to the greater speed which he has to keep up in order to avoid being pulled into the Sun by the gravitational attraction of that great body. The same rule applies to all the planets, which move more slowly as their distances from the Sun increase.

Next to Mercury comes Venus, which is at nearly three-quarters of the distance of the Earth, and has a year of about seven and a half of our months. Her path is nearly circular, more so than that of the Earth and much more so than that of Mercury.

Then comes the Earth, and outside that the planet Mars, which is half as far again from the Sun, and has a year nearly twice as long as ours.

The next conspicuous planet is Jupiter, which is more than five 'units' from the Sun, with a period of nearly twelve years. Outside the orbit of Jupiter is that of Saturn, at nine and a half units. This planet, which takes nearly thirty years to move round the Sun, marks the outer boundary of the Solar System, as it was known to the ancients. But, during the past century and a half, some important additions have been made to our list of members of the Sun's family. Thus, in 1781, Sir William Herschel, an amateur astronomer living at Bath, discovered a planet far outside the orbit of Saturn. This planet, which has been named Uranus, is at a distance of 19 units from the Sun, and has a year equal to 84 of ours. Some irregular movements of this distant body caused astronomers to suspect that it was being pulled out of its path by the attraction of a still more remote planet, and calculation finally led to its detection in 1846. It has been named Neptune, and is 30 units from the Sun, with a period of 165 years. Finally, as recently as 1930, a still more distant planet, Pluto, has been found, and many astronomers believe that it is only one of several which have eluded our search simply because of their great remoteness and consequently feeble light. Pluto can only be seen in a very powerful telescope and takes nearly 250 years to travel round the Sun.

But, to retrace our steps somewhat in time and space, the year 1801 saw the discovery of the first member of what is now known to be a very numerous family of small planets, which are much nearer to the Sun than the three bodies I have just

mentioned. Their paths lie mostly between the orbits of Mars and Jupiter, though several move well outside these limits in orbits that are less circular than those of the great planets. Between one and two thousand of them are known already, and most of them have been given separate names! Collectively, however, they are referred to as the Asteroids or Minor Planets.

We have seen how the motion of the Earth round the Sun brings a special set of stars into the night sky at each season of the year, and that, for at least hundreds of years together, there is no appreciable change in the appearance of the heavens in any particular month. So, if you have a set of star-maps, such as are published every month in some of the newspapers, you will always know what stars are visible at any time. But the movements of the planets have no special relation to the length of our year, so that, if you want to find them in the sky, you must either know the star-groups so well that you can at once recognize the presence of a strange object, or else you must look up their positions in an almanac for the date of observation, and mark them on the star-map before you start looking for them. When you think you have succeeded in identifying a planet you can generally make sure of the fact by noting that, unlike the stars, it does not twinkle.

Since the paths of Mercury and Venus lie inside that of the Earth, these planets can never appear very far from the direction of the Sun. They must therefore be looked for in the West after sunset or in the East before sunrise. If the Earth were

stationary Mercury would seem to come to the same position, on one side or other of the Sun, every 88 days, which is its period of revolution. Likewise Venus would perform her complete oscillation in 225 days. But the Earth is all the time moving round the Sun in the same direction, and this has the effect of making the to-and-fro motion of these planets less rapid. Exactly the same thing would happen in the case of three cyclists riding round a circular track, the one on the outside moving more slowly than his two fellows.

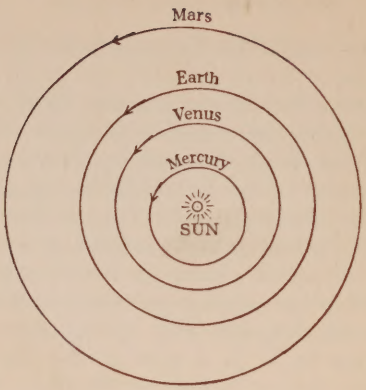
Mercury is so close to the Sun that, when visible in the evening, he disappears below the horizon before it is really dark, at least in temperate latitudes. Therefore the time available for seeing him is very brief, and a very clear sky is necessary if he is to be seen clearly against the bright glow of the early twilight. Venus, however, departs very much further from the direction of the Sun, and is often visible in a perfectly dark sky for some hours after sunset or before sunrise. Apart from this, she is a much brighter planet, in fact the brightest of them all, and will even throw a faint but definite shadow in the absence of the Moon.

When an interior planet, like Mercury or Venus, appears at its furthest from the direction of the Sun, it is said to be at its greatest 'elongation', and when it is in the act of passing from one side of the Sun to the other we say that it is in 'conjunction' with that body. If the planet is passing on the far side of the Sun, it is said to be in 'superior'

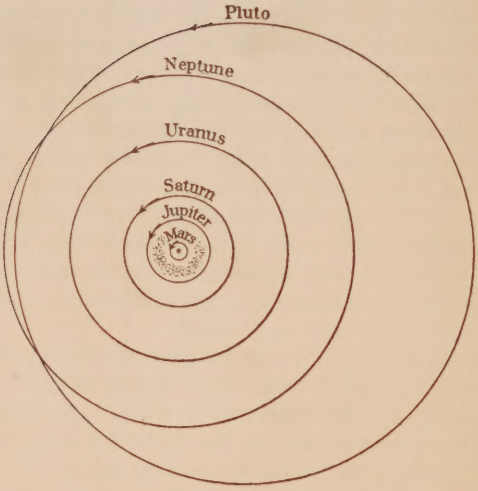
conjunction, and if on the near side, in 'inferior' conjunction.

The three other bright planets, Mars, Jupiter, and Saturn, may be found in any part of the sky and at various times of the night, since their paths lie outside that of the Earth. Mars can always be distinguished from the other two, in fact from all the planets, by his markedly reddish or orange tint. Like all the outside planets he is naturally seen at his best when the Earth is just passing him, and a glance at the diagram (Fig. 2) will show that at such a time he is in a part of the sky exactly opposite to that occupied by the Sun. For this reason a planet in this position is said to be in 'opposition' to the Sun. As the Sun is in the South at midday, it follows that a planet in opposition will be due South, or 'on the meridian', at midnight. It will then be rising about sunset and setting near sunrise, and so be visible all night. Later, as the faster-moving Earth leaves the planet behind, the latter will seem to draw in towards the Sun, on the far side of which it will ultimately disappear at the time of its conjunction. This is always a 'superior' conjunction in the case of an outer planet, as it cannot pass between us and the Sun, like Mercury and Venus.

Returning to the special case of Mars, we see from the diagram that, when in conjunction with the Sun, he is about five times as far away from us as at the time of opposition. One result of this is that his brightness varies very considerably, and, although he is always a very conspicuous object when at his nearest, there are times when he would



THE INNER PLANETS



THE OUTER PLANETS

FIG. 2.—THE SOLAR SYSTEM

scarcely attract any attention. The Earth passes close to him at intervals of rather more than two years, and if the paths of both planets were perfect circles, having the same centre, Mars would at such times be always at the same distance and therefore of the same brightness. But these paths, especially that of Mars, are ellipses (which may be described roughly as more or less elongated circles) and each has a different centre. The result is that the two orbits are much nearer together at some points than at others, and, if the Earth happens to pass Mars at one of these near-lying points, the planet appears unusually brilliant. This happens once in about fifteen years, or at every seventh opposition. At such times Mars may give slightly more light than Jupiter and thus be the second brightest planet, but more usually he occupies the third place.

Jupiter, when he shines in the midnight sky, is quite unmistakable, as no star approaches him in brilliance, and it is only when he is near conjunction with the Sun that he could possibly be confused with Venus. The Earth catches him up every thirteen months, so that oppositions of Jupiter are much more frequent than those of Mars. The changes in the brightness of this great planet are less marked than those of Mars, and there is no great difference in this respect between one opposition and another.

Oppositions of Saturn occur at intervals of very little more than a year, as he has only moved along a small part of his thirty-year journey round the Sun each time the Earth passes him. His bright-

ness is not nearly so great as that of Jupiter, but is sufficient to distinguish him from all but the most brilliant stars, and his steady light would decide the matter in case of doubt.

There is a peculiarity in the apparent motions of the outer planets which is worth noticing. Instead of moving steadily from West to East, which is the true direction of their revolution round the Sun, they seem to come to a standstill in the sky some few weeks before their oppositions, and then they actually move backwards, or Westwards, for a time, become stationary again, and finally resume their forward movement. This temporary check to their proper advance is caused solely by the more rapid forward motion of the Earth, which has its greatest effect at the time of opposition, when we are nearest to them. In the same way, when we are in an express and pass a 'local' travelling in the same direction, the slower train appears to be actually moving backwards. When a planet seems to be going Westwards in this way it is said to be 'retrograding', while its normal easterly motion is described as 'direct'. When it is momentarily standing still it is said to be at a 'stationary point'.

The orbits of the planets lie fairly nearly on the same level as that of the Earth, so that they seem to move among the same star-groups as the Sun does. This apparent path of the Sun is called the 'Ecliptic', for a reason to be explained in the next chapter, and the fact that the planets are always on or near to this line helps to make it easy to find them.

To the naked eye all the planets appear to be

single objects, but the telescope shows that most of them are accompanied by one or more smaller objects, which revolve round them in just the same way as the planets themselves revolve round the Sun. They are termed moons, satellites, or secondary planets. A planet with its satellites forms a sort of miniature of the Solar System, and the first discovery, by Galileo, of such an arrangement in the case of Jupiter, did much to accelerate the general adoption of the Copernican theory.

Neither Mercury nor Venus has any attendant. The Earth has one, the Moon. Mars has two, Jupiter nine, Saturn nine or ten, Uranus four, and Neptune one.

Newton's law of gravitation teaches that the speed at which a small body revolves round a large one depends on their combined mass and their distance apart. As the satellites in the Solar System are mostly very small compared with their primaries, their own masses can scarcely affect their motion and may therefore be neglected. And so, by simply noting their distances and periods of revolution, we can at once deduce the masses of the planets round which they revolve. This is perhaps the most important lesson which we learn from the satellites.

All the planets and their attendants are well defined globular bodies. But the Solar System contains other objects of a somewhat different character, known as comets. These are large diffuse bodies of small mass, revolving round the Sun in very much elongated orbits. Some are permanent members of the System, with periods between

three and nearly a hundred years. But most of them come from such great distances that it is impossible to be sure whether they belong to the System or not, since their periods, if any, are too long to be determined.

Moving in paths similar to those of the comets, and probably related to them also in other ways, are the meteors. These are, for the most part, exceedingly small bodies as compared with the planets and their satellites, and they are much too minute to be seen individually by the light which they reflect from the Sun. But they exist in countless myriads throughout the System, and it is probably the combined reflections from vast numbers of them which appear to us in the form of a faint glow in the West just after dark. This glow, which is also to be seen in the East before the morning twilight, is called the Zodiacal Light. The circumstances under which meteors may be studied as individuals will be dealt with in a later chapter, wherein also the physical appearances and nature of the planets, satellites and comets, as revealed by the telescope, will be described.

CHAPTER III

THE SUN AND MOON

Next to the Earth itself the Sun is, to us, the most important body in the Universe, for we depend upon his heat and light for our very existence. It is true that the interior of the Earth is intensely

hot; but very little of the heat reaches the surface, and it is certain that, but for the presence of the Sun, this planet of ours would be, to all intents and purposes, a frozen world. The oceans would be a mass of ice from top to bottom, and the land would be so frostbound as to be incapable of supporting any form of vegetation. Finally, even the very air we now breathe would be reduced to a solid state, so that all animal life would also be impossible.

To the philosophers of early times, as to other folk, the Sun was of interest chiefly because he appeared to be unique. To modern astronomers, however, he is of importance for precisely the opposite reason. So far as our observations can inform us, the stars are by far the commonest objects in the Universe, and it is now recognized that our Sun is nothing more than a fairly typical member of this vast class. He is unique only because his nearness enables us to make a more thorough study of him than of the others.

The distances of the stars are so great that they appear to us as mere points of light, even in the most powerful telescopes. But the Sun is near enough to present to us a large disc, which, in angular measure, is about half a degree in diameter. That is to say, there is room for something like 720 Suns, side by side, all along the horizon. As we know the distance of the Sun we can translate this apparent, or angular, size into real dimensions, with the result that the diameter is found to be 864,000 miles. This is more than a hundred times the diameter of the Earth, so that, if we picture the latter as a large grape about one inch in dia-

meter, the Sun would be represented by a globe nine feet across, such as would almost reach the ceiling of an average room if it rested on the floor. It would take more than a million Earths rolled into one to make a ball as big as the Sun. It is true that our world is one of the smaller planets, but even the largest, Jupiter, is hardly more than one-thousandth of the bulk of the star which occupies the centre of the Solar System.

The surface of the Sun is of an intense brilliance, greater even than that of the glowing carbons of an arc lamp, so that special precautions have to be taken before it can be examined with a telescope. But when the light has been reduced by a dark glass or by some reflecting device, we can obtain a comfortable view. We then find that the surface is not perfectly uniform in brightness, but consists of a very great number of separate cloud-like masses of flame, packed closely together like the pile of a carpet or rug. At a first glance these flames appear to be quiescent, but that is only because they are so large and distant that quite rapid movements seem to take a long time in producing any visible effect. Actually the whole surface is in a constant state of seething activity. The layer of flames is comparatively shallow, and between the bright masses there are much darker spaces. In certain places these gaps sometimes become so abnormally large that a dusky patch is produced, appearing like a hole in the general surface. Such a patch is known as a 'sun-spot', and may often be large enough to be visible to the naked eye.

A sun-spot is only a temporary phenomenon. Small ones often appear and close in again within a few hours, but those of the largest size (often large enough to contain our whole Earth many times over) may persist for weeks or even months. Meanwhile their outlines undergo constant changes, so that it may be quite difficult to identify a spot by its appearance alone after the lapse of a few days. As to the true cause of a sun-spot nothing is very definitely known, except that it represents a disturbance of a cyclonic nature, taking place near, and probably just below, the luminous surface.

Sun-spots had been seen occasionally with the naked eye in ancient and medieval times, though their true nature could not be appreciated. But they soon yielded a most important piece of information to the first users of the telescope, early in the Seventeenth Century. This was the fact that the Sun, like the Earth, is rotating about an axis, the period of rotation being between three and four weeks. But the strange thing about this rotation is that its period is not the same all over the Sun. The parts near the Equator have a period of about twenty-five days, but further North or South the rotation is much slower and is less by four or five days near the poles. This is a proof, if any were needed, that the Sun is not a solid body. It is, in fact, wholly gaseous, as we have reason to believe is the case with all the stars. The cause is, of course, the high temperature, which does not allow any substance known to us to exist in a solid or even liquid state. This is so even at the surface, which is the coolest part of the Sun.

Here the temperature is in the neighbourhood of 6000° Centigrade, while in the interior it is believed to be many millions of degrees on the same scale.

One of the most curious things about sun-spots is that they are periodic in their appearance. That does not mean that the outbreak of any particular spot can be predicted, any more than an individual summer thunderstorm can be foretold, but that there are times when spots in general are sure to be seen in greater or smaller numbers than the average. Observation has shown that the spots tend to appear in greater numbers, and generally of greater size, at intervals of eleven years. Why this is so no one has ever yet explained satisfactorily, but there is no doubt of the fact.

With very few exceptions the spots are confined to two zones of the Sun, one on either side of the Equator. Spots are very seldom seen exactly on this line, and never at the Poles. During the sun-spot 'cycle', as the eleven-year period is called, they tend to occupy different positions in the spot-zones, occurring nearer and nearer to the Equator as the maximum of numbers is approached. After it has passed the movement still continues, the spots becoming less and less frequent. Finally, while the scattered members of the dying cycle are appearing close to the Equator, the first spots of the new cycle are already appearing at the sides of the zones nearest the Poles—and so it goes on.

To the naked eye, or in the telescope, the Sun appears sharply defined, with nothing outside it in its immediate neighbourhood. But actually there

THE SUN
1928 September 25

THE SUN
1928 September 27

A SOLAR PROMINENCE

TOTAL SOLAR ECLIPSE
showing corona

is an extensive atmosphere which is only invisible to us under normal conditions because it is too faint to be seen in the glare of full sunlight. When, however, the dazzling surface is hidden by the Moon during an eclipse, this glare is removed for a short time, and the bright light of the surrounding sky is also greatly dimmed. Under these conditions the Sun's atmosphere can be clearly seen, and is found to be divided roughly into three portions.

The lowest part, which is very shallow, consists of metals and other heavy elements, all in the gaseous state. Above this is a layer of calcium vapour and hydrogen, the latter extending further from the surface on account of its lightness, and rising here and there in great jets or columns called 'prominences'. Lastly, extending a great deal further into space than the other layers, is the outermost atmosphere, or 'corona'. This is a diaphanous structure consisting of transparent streamers or jets of a silvery colour. It can only be seen properly during a total eclipse of the Sun, and its exact nature is still unknown. It is at least partly gaseous, as is shown by its spectrum, but a good deal of its light appears to be merely reflected from the Sun, and it probably consists largely of minute particles driven away from the surface by the pressure of light.

The outline of the corona is found to change with the sun-spot cycle. When spots are few the streamers are at their longest near the Equator and seem to stretch out to East and West of the Sun's disc like wings, while only a few short tufts are

seen at either Pole. But at or near a sun-spot maximum the streamers spread out pretty evenly in all directions round the edge of the Sun, like the petals of a daisy.

It is for the study of the highest and lowest layers of the Sun's atmosphere that expeditions are organized to observe total eclipses in remote parts of the Earth. The middle layer, of hydrogen and calcium vapour, can be studied almost as well at other times, by means of the spectroscope, which spreads out the dazzling light of the sky, and allows us to concentrate on the rays which come from these elements alone.

The Sun's surface is the seat of great magnetic disturbances, which manifest themselves especially in the neighbourhood of large sun-spots. How far these magnetic 'storms' are the cause or effect of such spots is not quite certain, but there is no doubt that both spots and storms are very intimately associated, and the latter undergo a change of character in the same eleven-year period, or rather in a period of twice that length. These disturbances in the Sun are so violent that their effects are felt even at the distance of the Earth, where they cause oscillations of the magnetic needle and sometimes even interfere seriously with our telegraph and cable systems. They also act upon the rarefied gases high up in our atmosphere, and cause them to give forth the coloured glow that is familiar to us as the 'aurora'.

The effects just mentioned are the only tangible ones which have so far been demonstrated to be produced on the Earth or its atmosphere by

changes in the Sun. Many attempts have been made to trace some connection between terrestrial weather and the occurrence of sun-spots, or variations in the Sun's total output of heat. So far, however, no definite relation has been established, which shows that the effects, if any, are very slight.

* * * *

An inhabitant of some other planet, writing a book on Astronomy, would not be likely to deal with our Sun and Moon in the same chapter; for, while the first is the undisputed head of the entire System, the second is a mere attendant of one of the smaller worlds that revolve round him. But there is some excuse for us to be illogical in this matter, because the Moon, small though she is, is too near to us to be ignored or to be given anything but second place in our description of the objects to be seen in the sky. She is, in fact, by very far our nearest neighbour in Space, revolving as she does round the Earth at a distance of less than a quarter of a million miles. This may sound far enough, but, astronomically speaking, it is a mere trifle. If the Earth were at the centre of the Sun the Moon's entire path would lie wholly within that body, with plenty of room to spare all round.

The diameter of our satellite is just over 2000 miles, or about $\frac{1}{400}$ of that of the Sun. By a curious coincidence her distance is also less in almost exactly the same proportion, with the result that both bodies appear to the eye as nearly of the same size.

The Moon's path round the Earth is not quite a circle, so that she appears a little larger at some

times than at others, though the difference is hardly large enough to be noticeable to the naked eye. But what is really striking is the regular series of changes which is constantly taking place in her apparent shape. These changes of outline, which are called 'phases', are simply the effect of alterations in her position with regard to the Sun, and can best be understood by reference to a diagram (see Fig. 3).

The Moon, like the Earth and other planets, is really a dark body, and is only made visible to us by the light which falls upon her from the Sun. It is evident, however, that the latter cannot light up more than one side of her at a time, so that she must always have a bright half and a dark half. When she lies nearly in the same direction as the Sun, it is the dark half that is turned towards us, and she is invisible to us for a day or two. This phase is called 'New Moon'. As she moves away from the direction of the Sun she comes into view in the West just after sunset, and we can begin to see a little of the illuminated side. She now appears as a crescent with the right-hand side lit up. In about a week from New Moon she has gone a quarter of the way round the Earth and we can now see half of the illuminated side. This is the moment of 'First Quarter'. A week or so later the whole of the sun-lit half is visible to us and the Moon is said to be 'Full'. She now rises in the East at sunset and is due South at midnight. After this she begins again to turn her illuminated face away from us, and within a week has reached her 'third' or 'last' quarter. It is now the left-hand

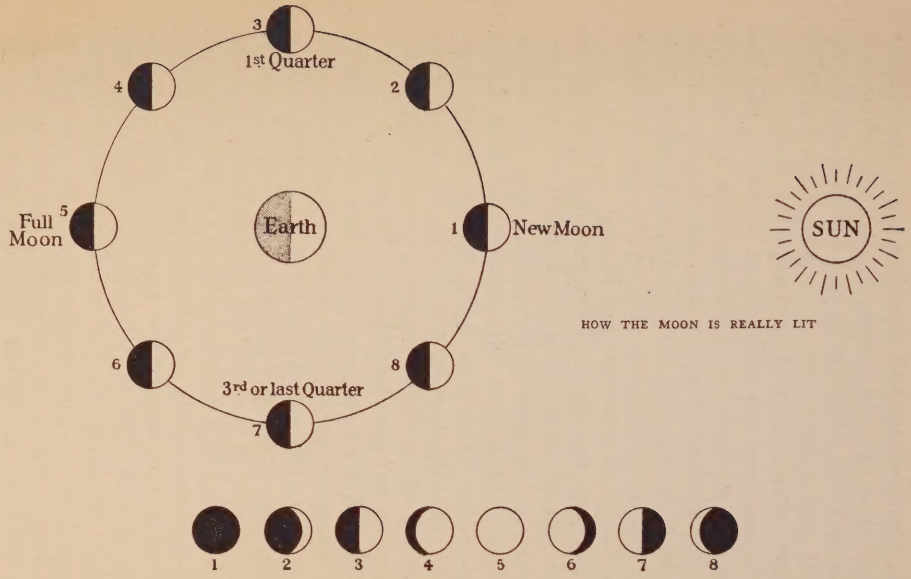


FIG. 3.—PHASES OF THE MOON

side that is lit up and she rises much later in the night than she did before. Finally she becomes a thin crescent, visible only just before dawn in the East, and a day or two later has reached another 'New' phase, just 29½ days after the first.

If you have any difficulty in following this description of the Moon's phases, or in understanding the diagram, the best way is to experiment for yourself by standing on one side of a bright lamp and getting a friend to walk round you holding a tennis-ball to represent the Moon.

Between the times of first and last quarter the dark side of the Moon is invisible to the naked eye, but it can be seen quite clearly when the bright part is reduced to a thin crescent. It then shines with a very faint grey light, which is really sunlight reflected to it by the Earth, the latter being nearly 'Full' to the Moon when she is nearly 'New' to us, as you can see from the diagram.

The Moon's path round the Earth is not quite on the same level as the Earth's path round the Sun. If it were, our satellite would cause an eclipse of the Sun at every New Moon, and would herself be eclipsed in the shadow of the Earth at every Full Moon. It is the slight tilt of the Moon's orbit which prevents this, and she generally passes above or below the Sun, or the Earth's shadow, as the case may be. But the direction of the tilt is constantly changing, so that at intervals she happens to be New or Full when she is near the points where her path is on a level with that of the Earth. Under these conditions an eclipse must occur. If it is one of the Moon it will be visible from every

part of the Earth which has our satellite above its horizon, because the darkening is a real one. It is otherwise with an eclipse of the Sun, where the darkening is only apparent and depends on the two bodies being in the same direction as seen by the observer. The Moon is so near to us that she appears in a slightly different direction as seen from various parts of the Earth; so she may appear to pass across the face of the Sun from, say, London, and yet be clear of his disc to an observer at the Cape of Good Hope.

The distances of both Sun and Moon from the Earth are, as we have seen, slightly variable, and this has an important effect on eclipses, especially those of the Sun. When the Moon is near to us she appears larger than the Sun, so that she is able to cover him completely as she passes in front of him. Such an eclipse is said to be 'total', and it is eclipses of this kind that have been so useful in revealing the faint parts of the Sun's atmosphere. If an eclipse of the Sun should occur when the Moon is at more than her average distance, and the Sun is not at his furthest, the disc of the Moon will be the smaller of the two. Under these conditions the bright rim of the Sun will be seen as a ring all round the black body of the Moon when the centres of the two bodies coincide. Such an eclipse is called 'annular', from the Latin *annulus*, a ring.

Whether an eclipse is total or annular in any part of the world, there will always be other parts where the Moon does not appear to pass centrally across the Sun's disc. In that case only a portion

of it is covered, and the eclipse is said to be 'partial' for those places. The Sun's apparent path in the sky is called the 'Ecliptic' because it is only when the Moon is on or near that line that eclipses can occur.

The Moon's motion in her orbit has been so carefully studied that it is possible to predict the time of an eclipse several years ahead within a few seconds of time. But this is not done without a great deal of trouble, because the motion is very far from being simple and regular. All sorts of causes, into which I need not enter, combine to make it variable, and even now some of them are not completely understood.

Before the days of watches and portable clocks, navigators used to get their time from the Moon's position among the stars, so it was a matter of great practical importance that its place in the heavens should be accurately predicted for every hour of the year. This was, indeed, the chief reason for the establishment of the Royal Observatory at Greenwich in 1675, and that is why this institution has always been under the control of the British Admiralty.

When we speak of a small body, like the Moon, revolving round a larger body, like the Earth, the description is not quite accurate. What really happens is that both bodies are revolving round a point somewhere between their centres, where the masses of both just balance one another. This point is called the common 'centre of gravity' of the two bodies and is always nearer the larger of the two. You can make a model to illustrate this

by taking a long thin stick, or a knitting needle, and fixing a small ball of putty or plasticine at one end and a much larger one at the other. If you now try to suspend the stick or needle in a loop of string you will have to bring the latter much nearer to the larger ball before the two will lie on the same level. The point at which the two balls are made to balance in this way is their common centre of gravity, and if you now twirl them gently round this point you will have a rough idea of how the Moon and the Earth are moving.

The Earth is eighty times as heavy as the Moon, so the point of balance is eighty times as far from the centre of the Moon as from that of the Earth. Actually this brings it right inside the body of the latter, so you see that it is *almost* correct to say simply that the Moon is doing all the revolving. The same is true of the Sun and planets in an even greater degree, because the central body so greatly outweighs all those which revolve round him.

I have mentioned in an earlier chapter that the strength of the attraction between any two bodies depends upon their distance apart. Now one side of the Earth is 8000 miles nearer to the Moon than the other side, so that the different parts of the globe are being pulled unequally towards our satellite. The result is that the whole body of the Earth is undergoing a constant distortion. This distortion is very slight, because our world is such a rigid body, but it is otherwise with the oceans, which respond much more readily to the pull. The sphere of water therefore tends to become elongated in the direction of the Moon, and this

is the cause of the tides. The Sun acts in the same way, but the tides which he forms are not so high. This is not because the pull is less, but because the *difference* of attraction over a distance of 8000 miles is so small compared with the great space which separates us from the Sun. When the Sun and Moon are pulling in the same straight line, as at New and Full Moon, the tides are specially high, and are known as 'Spring' tides. But at the Moon's first and last quarters each body tries to flatten out the tides produced by the other, so that the changes in the level of the water are smaller. These lower tides are called 'Neap' tides.

The smallness of our distance from the Moon enables us to get a very good idea of what sort of a world she is. Even the naked eye shows clearly some of the larger features of her surface, consisting of irregular light and dark patches. The same ones are always to be seen, which shows that the markings are permanent and that the Moon turns always the same face towards us. To do this it follows that she must turn her back in succession on all the stars in front of which she passes in her journey round the Earth; which is another way of saying that she rotates and revolves in the same period of time. We can therefore never see the other side of the Moon, but it is reasonable to suppose that it would have much the same general appearance as the side we see.

What we actually observe with a telescope on the face that is turned towards us is a bare, rocky surface, devoid of air or water, and consisting partly of mountainous regions and partly of nearly

level plains. The latter are the dark patches which we see with the naked eye, and the brighter parts are the highlands. We can measure the heights of the mountains by noting the lengths of their shadows, and their altitude above the plains proves to be about the same as that of our own peaks above sea-level.

The most striking thing about the mountain-masses of the Moon is that they are mostly of circular outline, like great saucers with raised rims, and sometimes with a small peak in the middle. These circular structures are of all sizes, from about 150 miles across to less than a quarter of a mile, which is the smallest that can be seen in our best telescopes. They occur in thousands all over the visible surface of the Moon, and their real nature has been a puzzle to astronomers ever since the invention of the telescope. There is nothing quite like them on the Earth, and, although it used to be thought that they represented the remains of extinct volcanoes, this view has of late years been losing ground, and many astronomers now believe that the so-called lunar 'craters' are cavities produced by the explosive impact of solid bodies of different sizes in past ages.

As the Moon has no atmosphere, there is nothing to temper the Sun's heat by day or to keep it in at night. So the range of temperature is enormous, and this alone, apart from the absence of air and water, would be sufficient to make animal and vegetable life impossible. Whether this was always so or not we cannot say.

CHAPTER IV

MORE ABOUT THE PLANETS

To the naked eye the planets are merely points of light, of different degrees of brightness, moving against the background of the stars. But, seen in the telescope, they are worlds like our own, presenting measurable discs from which their real dimensions can be deduced, and on which temporary or permanent markings can generally be made out. It is because they are near enough to appear as discs that the planets so seldom twinkle. The ripples in our atmosphere which cause the scintillation of the stars are usually not violent enough to affect the general steadiness of the large bundles of light-rays which reach us from the discs of the planets. In the same way the running water of a brook appears to agitate and sometimes almost to obliterate the smaller pebbles on the bottom, while the larger stones remain steadily in view.

The planet Mercury is a particularly difficult object to observe in a telescope. He is so close to the Sun that, in most countries, he can never be seen after dark; and even then he is sunk much too deeply in the horizon vapours to appear sharply defined under high magnification. He must therefore always be observed in broad daylight, with the Sun more or less high in the sky, and under these conditions the air is seldom sufficiently tranquil to allow of a satisfactory view. Another difficulty is that Mercury only presents to us a fully illuminated disc when he is at his furthest from

the Earth, on the other side of the Sun. He has, in fact, phases like the Moon, and, as he lies between us and the Sun when at his nearest, his bright half is then turned away from us. At either elongation he appears as a half-moon, and it is then that the best average views of his surface are obtained.

Under the most favourable conditions we see Mercury in the telescope about as well as we see the Moon with the naked eye, and observation seems to indicate many points of resemblance between the two bodies. The surface of Mercury, like that of the Moon, is in general somewhat dusky, and this fact, taken in conjunction with the negative evidence of the spectroscope, makes it almost certain that the planet has little or no atmosphere. Permanent dark patches, like those seen on the Moon, are visible here and there, and, as they never appear to pass from the bright to the dark side of the planet, it follows that Mercury, like the Moon, keeps the same face constantly turned to the body round which he revolves. In other words, his day and his year are of equal length—88 days.

Mercury is a very small planet, being barely 3000 miles in diameter, or less than half again as large as the Moon. This is probably the reason why he has no perceptible atmosphere, as the particles of air would tend to escape into Space with so small a gravitational pull to keep them down; and the same applies to the Moon and all smaller bodies. Mercury is so close to the Sun that his surface, unprotected by any atmospheric cover-

ing, must be raised to a temperature far above the boiling point of water, and it therefore follows that no form of organic life known to us could possibly exist on the planet.

Venus, when at her brightest, is the most splendid object in the whole sky, with the exception of the Sun and Moon. But in a telescope she is rather disappointing. Being further from the Sun she can be observed more conveniently than Mercury, and she is quite bright enough to be seen well in full daylight. She can, in fact, be often seen with the naked eye at midday, and is actually too dazzling to be observed comfortably with a telescope after dark. Like Mercury, she exhibits phases and shows us least of her illuminated surface when she is closest to us. She is nearly as large as the Earth, being 7600 miles in diameter, and, even when at her furthest from us, presents quite a large disc in a big telescope.

Our real difficulty in finding out much about Venus is caused by the extensive atmosphere which surrounds her. This mantle reflects the Sun's light very strongly, and is, in fact, mainly responsible for the great brilliance of the planet; but it effectively prevents our obtaining any clear view of her real surface. Ill-defined dull patches are occasionally seen, but they are not permanent in shape or position and probably represent nothing more than partial breaks in the cloudy covering. The result of this want of definiteness in the markings of Venus is that astronomers have never been able to determine with certainty the period of the planet's rotation. Some have concluded that, like

Mercury, she always turns the same face to the Sun, while the spectroscope shows that the period can scarcely be much under a fortnight; and this is all that seems to be known with certainty. So we have not much data for speculation as to the habitability of Venus. The most we can say is that the sun-lit half must be very hot, much more so than is the case with the Earth, and that the nights must be very cold. The longer the rotation period the greater must be these extremes of day and night temperature, and although the thick atmosphere may do much towards keeping out the heat by day and keeping it in at night, it seems probable that parts of Venus would be scarcely habitable. But this would not necessarily be the case all over the planet.

The paths of Mercury and Venus do not lie on the same plane, or level, as that of the Earth, so that these planets generally appear to pass North or South of the Sun at the times of their inferior conjunctions. But occasionally the Earth is so placed that such a conjunction occurs when one of the bodies is very little above or below the critical level, and it will then be seen to pass across the face of the Sun as a round black disc. While the planet is projected on the Sun in this way it is said to be in 'transit', and this happens every few years in the case of Mercury. But transits of Venus are much more rare, and occur at intervals of over a century, at the end of which time there is generally a pair of transits, eight years apart.

When Venus passes between us and the Sun she is nearer to us than any of the other large planets,

and her direction is easily measured against the solar disc. So transits of Venus were at one time carefully observed for the purpose of finding the scale of the planetary system, in the manner explained in a previous chapter. However, better methods are now available, and it is doubtful whether any future transit will be observed with this object.

Mars is a much more easy planet to observe than either of the two which I have just described. This is chiefly because when he is nearest to us he presents a fully illuminated disc, since we are then on the same side of him as the Sun. At such times he appears, in a powerful telescope, a great deal larger than the Moon does to the naked eye, and we get a more detailed view of his surface than we can do in the case of any other planet.

The first thing to strike the eye is the peculiar reddish-orange coloration of the general surface, very different from the snow-white reflection given by the atmosphere of Venus. On this bright background lie several dusky patches and streaks of a grey or bluish-grey tint. They are evidently permanent features, lying on the actual surface, for they are always seen in the same relative positions and are repeatedly brought into view by the rotation of the planet, which takes place in about 24 hours 37 minutes. Thus day and night on Mars are of very nearly the same length as on the Earth. The two planets are also alike in having their axes tilted by nearly the same amount, so that Mars enjoys seasons like ours, though of about twice the length, as he takes nearly two years to go

round the Sun. His diameter is just over 4000 miles.

In the early days of the telescope it was thought that the dark markings represented seas; but modern observations do not support this view, for, while the positions of the markings do not alter, they undergo certain changes of outline and colour from time to time, and can therefore scarcely be areas of deep water. Some of the changes observed are related to the seasons of Mars, while others appear to be irregular. The general opinion of astronomers now is that there are no large collections of water, like our oceans, on Mars, but that the dark areas probably represent patches of vegetation of some sort.

That Mars is a much drier world than the Earth is further evident from the great rarity of anything like our heavy rain-clouds, which would appear as dazzling white patches as seen through our telescopes. But it is certain that the planet is not entirely without moisture, for large masses of snow or hoar-frost are visible at either Pole, and these regularly wax and wane in size with the seasons, as happens on our own Earth. The presence of these polar patches shows that Mars must possess an atmosphere of some sort, and indeed its presence is further confirmed by the evidence of photography and the spectroscope. It is, however, quite certain that there is much less air on Mars than on the Earth, and one of the results of this is that much greater extremes of temperature between day and night are experienced there.

The amount of heat received by the surface of

Mars has actually been measured, probably with fair exactness, and it appears that while the temperature at midday on the Equator is something like 60° or 70° Fahrenheit, it is always below freezing-point in the early morning and late afternoon. At night it must be very far below zero. Whether there is any form of animal life on Mars will probably never be known, at least from the observations of astronomers. All that seems certain is that the conditions are unsuited to *our* particular forms of such life.

Mars has two tiny moons, each but a few miles in diameter and visible only in large telescopes. These little satellites are unusually small in relation to their parent planet. It is just the opposite in the case of our Moon, which is so large as compared with the Earth that she ought almost to be regarded as a sister planet rather than a satellite.

The minor planets, or asteroids, are not of much interest as telescopic objects. The four which were the first to be discovered, Ceres, Pallas, Juno, and Vesta, show tiny discs in our largest telescopes; but all the others are mere points of light, mostly very faint. The diameter of Ceres, the largest, is nearly 500 miles, but the majority are less than one-tenth of this size, and some of the smaller ones are between one and three miles in diameter. The paths of most of them lie between the orbits of Mars and Jupiter, but some extend partly or wholly beyond these limits in either direction. A few asteroids occasionally approach us more closely than Mars, and one of these, called Eros, has been used at two of his approaches as a means of

measuring the scale of the Solar System. Two more, discovered as recently as 1932, come still nearer than Eros, but their orbits have not yet been studied with sufficient fulness to be made use of in this way. One of them is the first minor planet known to have its path partly within that of the Earth. In fact, when nearest to the Sun, it actually passes within the orbit of Venus.

Jupiter is by far the largest member of the Sun's family; larger, in fact, than all the others put together. His diameter is nearly 90,000 miles, or more than eleven times that of the Earth, and it would take over 1300 globes the size of ours, rolled into one, to make a planet as large as Jupiter.

A very small telescope, such as can be held in the hand, is sufficiently powerful to show the disc of this great planet, which was first seen in this way by Galileo in 1610. Quite a low power will also show that the disc is by no means truly circular. The slight flattening of the Earth at its Poles is well known. It is due to rotation and amounts to about 27 miles, or nearly $\frac{1}{300}$ of our planet's diameter. The flattening of the globe of Jupiter is much greater than this, being 6000 miles, or $\frac{1}{15}$ of his greatest breadth. This fact alone would be sufficient to indicate that Jupiter is spinning round at a great rate, and observations of the markings on his surface show that the length of his day is just under ten hours, as compared with our twenty-four.

The markings which give us this information are of quite a different character from those of Mars. In the first place, they are much more

regular and symmetrical, taking the form of alternate bright and dusky belts lying parallel to one another like the lines of latitude on a globe. Further, they are scarcely at all permanent in their details, developing spots and other irregularities which come and go in quite short periods of time. In this way they recall the behaviour of the spots on the Sun or the cloud-formations of our own atmosphere. In fact, it is plain that they are not features of a solid surface but are rather of an atmospheric nature. This idea is confirmed by the fact that markings in different latitudes rotate in different periods, just as is the case with the sun-spots. Features near the planet's equator gain over five minutes in each rotation on those a few degrees North or South of this line, and for this reason alone the face of Jupiter never looks quite the same for two nights together.

In a small telescope the dusky belts appear grey and colourless, but a large instrument reveals a variety of colours in them. The predominant tone is brown, but the actual colour is very variable and is generally not quite the same for any two belts. Often a strong reddish tint is observed, while at other times the belts appear merely tawny or coffee-coloured. The light spaces between the dark belts are neither uniform nor constant in their brightness, but, with the exception of the equatorial regions, they are generally free from any special tint.

No one has yet given a satisfactory explanation of what we actually see on the surface of Jupiter, and it is still more difficult to conjecture what lies

below. Bulk for bulk, the planet weighs much less than the Earth, and it has been suggested that he is wholly molten or even gaseous, with no solid surface. The movements in his atmosphere certainly suggest the possibility of a heated region beneath; but direct measurements have shown that such heat, if really there, does not penetrate in any quantity to the surface that we see. For the present we have to be content to study the changes and movements in that cloud-like covering, in the hope that they may some day give a clue to what is going on beneath it.

Jupiter is accompanied by nine satellites. The four largest, which were the first objects discovered with the newly invented telescope in 1610, can just be seen in a good prism binocular, appearing like tiny stars strung out in a nearly straight line to right or left of the planet, or on both sides at once. With a large telescope their real discs can be seen and their diameters measured. Two of the four are about the same size as our own Moon, while the other two are half again as large, or about the size of Mercury. They revolve round their primary in different periods, and it is interesting to watch their movements from night to night with a small telescope.

Their orbits have been carefully studied, and it is possible to predict very closely the times at which they will pass in transit across the face of the planet or be eclipsed by his shadow. The predictions of these occurrences were at one time used by navigators and explorers for the purpose of determining the correct time. Better methods are now available,

but a very interesting and important fact was brought to light soon after the first calculations of the positions of the satellites were made, in the Seventeenth Century. It was noticed that, when Jupiter was on the far side of his orbit, from the Earth, the eclipses of the satellites occurred about a quarter of an hour later than their predicted times, though the error practically disappeared when Jupiter came round to opposition again. The Danish astronomer Römer hit upon the correct explanation, which is that the lag of a quarter of an hour represents the extra distance over which the light has to travel to the observer. The diagram of the Solar System will show you that this extra distance is equal to the diameter of the Earth's orbit, and, as this is known in miles, it is possible to deduce the speed at which light travels. It turns out to be about 186,000 miles per second, at which rate it takes just over eight minutes to reach the Earth from the Sun. The importance of this discovery of the finite velocity of light will be better appreciated when we come to consider the stars, and the Universe as a whole.

Saturn is the second largest planet in our System, being 75,000 miles in diameter. As he is further away from Earth and Sun than Jupiter he appears much smaller and fainter, and it is therefore more difficult to examine his surface in detail. It is possible, however, to make out that, with his belts and polar flattening and his ten-hour day, he is very similar to his big brother. He has the distinction of being lighter, for his bulk, than any other planet, which adds to our difficulties in

trying to guess what he is made of. Beyond the facts that he has a dense atmosphere nearly as white as snow, and that his visible surface is intensely cold, we know practically nothing.

What really makes Saturn unique among all known objects is the wonderful system of rings which surrounds him. These structures, which do not touch the planet at any point, lie on a level with his equator. There are at least three of them, and there is a narrow space between the two outer ones. The inner edge of the innermost ring is many thousands of miles from Saturn's surface, and the extreme span of the whole system is 174,000 miles. In comparison with their width the rings are extremely thin and flat, being certainly less than fifty miles thick. Occasionally they are turned edgewise to our view, and they then actually disappear for a short time, as their edges are not sufficiently broad to reflect enough sunlight to make them visible.

It is known that the rings are not solid but consist of myriads of small particles, possibly ice-crystals, revolving together round the planet like so many satellites. They are most thickly clustered together in the middle ring, which consequently appears the brightest of the three. The outer ring is less bright, almost certainly because its particles are more widely separated. The effect of this is to make the ring virtually transparent, and a star was once actually seen through it. The innermost ring is the faintest of all, and is only clearly seen in a large telescope. The axis of Saturn is tilted at an angle to his path round the Sun, so that we some-

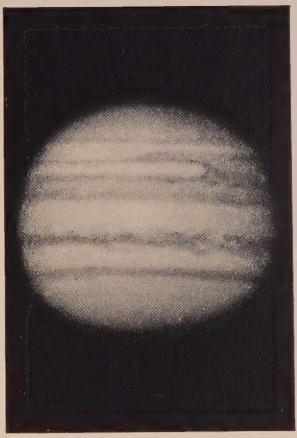
times see the Northern and at other times the Southern side of the rings.

Saturn has at least nine, and possibly ten satellites, but they are not conspicuous objects like those of Jupiter, and are not specially remarkable in any way. Most of them vary more or less in brightness according to their positions in their orbits, and observations of these changes have made it practically certain that, like our Moon, they always turn the same face to their primary. The same is almost certainly true of the four chief satellites of Jupiter.

Uranus and Neptune are a pair of very similar planets. Each is about four times the diameter of the Earth, Neptune being slightly the larger of the two. Their distance is so great that very little can be made out on their tiny discs, but belt-like markings, similar to those of Jupiter and Saturn, have been seen with large telescopes. It is probable that they are very similar to these larger planets in general constitution, especially as their surfaces reflect about the same proportion of sunlight, and they are of the same sort of lightness, bulk for bulk. Incidentally it will have been noticed that the zone of asteroids forms the dividing line between two different types of planet, those within it being small and heavy, while those outside are large and light.

The spectroscope shows that Uranus rotates on his axis in just under eleven hours, and the remarkable thing about this axis is that it lies almost level with the planet's orbit. Indeed, the tilt is actually a little more than a full right angle, so that Uranus

MARS



JUPITER

SATURN

A COMET

may be said to rotate backwards as compared with the other planets. The same is true of the revolution of his four satellites, which move nearly in the plane of his equator.

Neptune's single satellite also revolves in the same backward direction, and from this it may be inferred that the planet itself rotates in the same way. The length of his day has been estimated from slight variations in his light and from changes in the position of the satellite's orbit, and is found to be rather less than sixteen hours.

Pluto is so distant that no telescope will show his disc. From his apparent brightness, however, his size is inferred to be about equal to that of Mars. Nothing is yet known as to his period of rotation, but this may possibly be deduced in the future from variations in his brightness, supposing that some parts of his surface are more dusky than others.

The smallest of the planetary bodies which reflect the Sun's light into our telescopes is about one mile in diameter. But there is plenty of evidence to show that this is not really the lower limit of size for members of the Solar System. Travelling round the Sun in elongated orbits are vast numbers of very much smaller bodies. The great majority are only a small fraction of an inch in diameter, and even the largest is too small to be visible by the light which it reflects from the Sun. But when, as is constantly happening, these small bodies cut through our atmosphere, the sudden resistance offered by it to their great speed causes them to be raised to a white heat, and they thus become visible to us for a few seconds.

These meteors, or 'shooting stars' as they are popularly called, are generally at heights of between thirty and eighty miles above the Earth during the time that we see them. Usually they are burnt up completely, but the larger ones often reach the surface of the Earth and can thus be picked up and examined. Some are then found to be stony bodies, more like pieces of terrestrial rock, while others are largely metallic, being composed chiefly of iron and nickel. Specimens of both kinds may be seen in most of our large museums, and there is a particularly fine collection in the Natural History Museum at South Kensington.

Meteors generally appear singly in the sky, and on an average night you may see three or four every hour that you watch. But on certain nights of the year the Earth passes through quite a stream of meteors, so that fifty or sixty may be counted in a similar period; and, on rare occasions, when the meteor-stream is particularly thick, a regular 'shower' of shooting stars may be observed, all radiating from the same point like the spokes of a wheel, with half a dozen or more appearing at the same time. Really they are moving in parallel lines, but they seem to spread out in the sky because they are rapidly changing their distance from us. In the same way, if you look down a long straight corridor, the edges of the floor and ceiling seem further apart in the foreground than in the distance, though they are really parallel to one another.

Some of the largest meteors, or 'meteorites', which have reached the Earth weigh many tons,

and a few have been so large that the explosion caused by their impact has produced crater-like depressions hundreds of yards in diameter. This fact, which has only been confirmed in recent years, lends colour to the theory that the lunar craters owe their origin to similar falls on a still larger scale.

The appearance of the Comets is quite unlike that of any other bodies in the Solar System. Instead of presenting sharply defined discs or points of light they are diffuse transparent objects, with hardly any signs of solidity. Though most of them are of great bulk, many times larger than the biggest planets, stars can be clearly seen right through them, so that the actual amount of matter contained in them must be very small. In fact, no effects on other objects, due to a comet's mass, have ever been detected. Generally speaking they are roughly globular in shape, with a more or less bright condensation, or 'nucleus', at the centre. This is the appearance of a comet when it is far from the Sun, and at such a time most of its light seems to be simply reflected sunlight. But as it approaches the Sun in its elongated orbit its matter is acted upon by that body, and it begins to give out a certain amount of light of its own. At the same time some of the finer particles are driven away from it by the repelling effect of the sunlight, so that it develops a streamer, or 'tail'. If the comet is a large one and passes very close to the Sun, the 'head' may become very bright and the tail very long and conspicuous. Such comets are clearly visible to the naked eye, sometimes for

many weeks together; but the great majority are faint objects, visible only through a telescope.

In the cases where a comet's path cuts that of the Earth it has always been found that there is a stream of meteors moving in the same orbit, so there is evidently a close physical connection between the two classes of object. The exact nature of the connection is not known, but it is thought probable that the nucleus of a comet is really nothing but a compact cluster of meteors, and that those spread more sparsely along the orbit are stragglers which have left the parent mass. The spectroscope has shown that most of the bulk of a comet is made up of light gases, many of which are familiar to us on this Earth. But when the nucleus is strongly heated near the Sun, the glow of metallic vapours is seen, which supports the theory of its meteoric nature.

Comets and meteors are perhaps alike to be regarded as the débris of the Solar System, left over after the formation of the more massive planetary bodies.

CHAPTER V

OTHER SUNS

Behind the Sun, Moon, and planets lies the background of the starry sky. The shining points with which it is studded seem, on a general survey, to be distributed in a more or less haphazard fashion all over the celestial sphere, with only here and there a marked tendency to form compact groups,

or 'clusters'. However, for convenience of description it has been the practice from the earliest ages to divide the stars into arbitrary groups, or 'constellations', and the names given to them have either been prompted by some real or fancied resemblance in their outline to some terrestrial object or animal, or else they have been chosen to honour and perpetuate the names of the gods and heroes of ancient mythology. As an example of the first type we may take the constellation Scorpio (the scorpion), the outline of which very strikingly suggests the shape of that animal, while the second type may be represented by Perseus and Andromeda, neither of which suggests the least resemblance to a human form.

The only two things that the naked eye can make out about the stars as individuals are that they differ very strikingly in brightness and to a less marked extent in colour. Taken with their positions these two characteristics, especially the first, help to identify the various stars; and for the past two thousand years astronomers have agreed to divide them into various classes, or grades, called 'magnitudes', according to their brightness. Thus the brightest stars are said to be of the 'first magnitude', those rather less bright of the 'second magnitude', and so on.

The early astronomers, who first incorporated this subdivision of brightness in their catalogues, recognized six magnitudes, comprising all the stars readily visible to the naked eye, from the brightest to the faintest. Modern investigators have shown that a star of a given magnitude is

about two and a half times as bright as the next below it, and this ratio has been adopted and extended to still fainter stars, visible only in telescopes.

Our largest instruments can photograph down to the 21st or 22nd magnitude, and if you work it out you will find that such a star has less than a hundred millionth of the brightness of one of the first magnitude. Research workers have found it necessary to subdivide stellar magnitudes still further, so that each stage is divided into ten or even a hundred parts, and in this way it is possible to measure and record slight differences of light with great accuracy.

Seeing that the stars are of such varied degrees of brightness it is natural to enquire what is the cause of the differences observed. Are they due to inequalities of (1) distance, (2) surface brightness, or (3) size? Clearly all these three characteristics must have their effect on the light of a star as we see it, and if we can determine any two of them, the third must always follow.

Before the invention of the telescope, astronomers had practically made up their minds that to measure the distance of a star was a hopelessly impossible task. The apparent fixity of the constellation figures, in spite of the motion of the Earth, had shown that the distances involved must be very great, far exceeding those of the planets. In fact this fixity was one of the chief stumbling-blocks in the way of general acceptance of the theory of Copernicus, for it then seemed absurd that any object could be so far away that the Earth

could travel millions of miles round the Sun every year without producing some apparent shift in its position.

Even after the telescope came into use the problem remained insoluble for more than two centuries. It was found that even under high magnification, and employing the 186,000,000-mile base-line of the Earth's orbit, star after star refused to show any displacement. Finally, about a century ago two investigators, one at the Cape and the other in Germany, succeeded in detecting the long sought shift, each in a different star. Since that time instruments and methods have improved, and many hundreds of stellar distances have been measured, mostly by photographic means.

The delicacy of such measurements will be apparent when it is realized that the greatest annual displacement observed amounts to only $\frac{1}{1250}$ of the apparent diameter of the Moon. Or, to put it in another way, this is just how big our whole orbit appears, as seen from the nearest star. Light takes over four years to reach us from this point, and measures can be made, with increasing roughness, up to nearly a hundred times this distance. After that the triangulation method breaks down, as the quantities are too small to measure. We shall see later, however, that other means are available for getting a very fair idea of the distances of bodies vastly more remote.

Even the nearest star is too distant to show a definite disc in our most powerful telescopes. It would seem therefore as if we had no chance of

estimating the brightness of its surface, or its diameter. But here the spectroscope can help us, for this instrument, by spreading out the light of each star, shows us how much light of each colour there is in it, and from this it is possible to deduce the surface temperature and brightness from the known laws of physics. From such studies it has been found that, in general, the colour of a star, as seen by the eye, is an indication of its temperature and of the 'candle-power' of every square inch of its surface. Thus the white stars are the hottest, the yellow ones cooler, and the red stars coolest of all.

Now if we can measure the distance of a star, and at the same time say how intense a light its surface is giving out, we can estimate just how large that surface must be to shine with its observed brightness at that distance. This process of measurement and reasoning has been applied to a great number of stars, and we have thus obtained a definite answer to our question—why are the stars of different brightness?

The answer is that all three factors—distance, surface-brightness, and size—enter into the question; and, as all these are found to vary, it is impossible to tell very much about any individual star from a study of its apparent brightness alone. It appears that, although *in general* the stars are roughly similar to our Sun in size and total brightness, there are large differences between individual stars. Some are found to be much brighter and others much fainter than the Sun. In certain cases we can measure the mass of a star, in a manner to

be explained in the next chapter, and it is then found that this particular feature is much more nearly the same for all the stars than is their total brightness, or 'luminosity'. Now, with stars of the same surface brightness, these differences of luminosity must correspond to differences of diameter. But we have seen that the masses are not widely different, and we are therefore driven to the conclusion that, bulk for bulk, the stars must be of very different weights; which is another way of saying that they differ in 'density'.

Proceeding on these lines we have been able to accumulate a great amount of data from the rather limited number of stars that are accessible to the necessary measurements and examination. What we have obtained is sufficient to give us a very good general idea of the masses, densities, luminosities, diameters, and temperatures of these examples; and, as we have no reason to suppose them to be exceptional, we have ventured to generalize on the strength of what we have learnt. We have, in fact, been led to a rough classification of stellar types, and can even try to arrange them in such an order as may, we hope, represent the story of their growth and evolution.

The life-history of a star is a matter of untold millions of years, and we cannot actually observe any steady change from day to day, or even perhaps from century to century. But it is not really necessary to do so. By looking at the dandelions in a field—some in bud, some in full bloom, and others going to seed—we can in a moment picture a series of changes which would take days or even

weeks to take place. So, in the heavens, we can safely assume the existence of an evolution of which we can only observe examples of isolated stages.

That the age of a star is connected in some way with its colour is an idea that occurred to astronomers quite a long time ago, and it was further realized that the colour was at least partly dependent on the temperature of the body emitting the light. Both these ideas were confirmed when, in the second half of the Nineteenth Century, it became possible to make a close study of stellar spectra. It was found that these spectra could be fitted into a regular and continuous sequence following closely the differences of colour between the various stars. It then seemed quite an easy matter to read in this sequence the life-history of a star. It was supposed that stellar birth consisted in the coming together of a mass of scattered gas and finely divided material. The packing together of this matter under the influence of its own gravitation would raise its temperature so highly that the whole would shine as a white-hot body. As time went on this heat would be radiated away into space, causing the star to become cooler and therefore less white. The same thing is, of course, familiar in the cooling of a mass of white-hot iron, which gradually becomes yellow as its temperature falls. The yellow star was then supposed to become orange and finally red; after which would come a time when the temperature had fallen so low that no light at all was given out, and the star would end its life as a dark, cold body. In accordance with

this idea it became customary to refer to the white stars as being of 'early' type, while the red ones were said to be of 'late' type.

This apparently simple and satisfactory classification of the stars according to their supposed age was rudely upset when later observations showed that, while the white stars were much alike in size and luminosity, the red ones were of two very different kinds. Though their colours were the same it was found that some were exceedingly large bodies, of great luminosity but of very low density, while others were strongly contrasted with them, being relatively tiny globes, so faint that only those fairly near to us could be seen at all. The same sort of difference, though much less marked, was found among the orange stars, and even to a slight extent among the yellow ones. The names 'giant' and dwarf' were appropriately adopted to distinguish between the two contrasted types into which the highly coloured stars appeared to be divided, and it was seen at once that, with such marked differences, they could not very well be supposed to represent the same stages in a star's life-history. So it became necessary to revise our ideas in a way that would fit in with the new facts which had been brought to light.

The current theory fits in very much better with these facts and is certainly more nearly correct, though it still leaves some points unexplained and will probably have to be revised from time to time. It is now believed that the older theory tells only half the tale of a star's life, giving us merely a picture of what happens between full growth and

death, leaving out the story of its birth and development towards maturity. That is to say, the white stage marks not the first but the middle period of the star's existence. The commencement, by a coming together of diffuse cold matter, is admitted, as in the earlier theory. But it can be shown, by a knowledge of the laws governing the behaviour of gases, that the collection of matter would not immediately be raised to a white heat. The process of contraction under gravitation would be much too gradual, and when the star first became hot enough to give out light it would be red in colour and still far from compact. So we have here the stage of great size, deep colour, and low density which is characteristic of the red 'giant' stars. Later, as contraction increases, the temperature is raised and the star becomes yellower and more dense.

What happens after this depends on the amount of matter in the star, that is upon its mass. If this is large, the contraction due to gravitation will be so strong that a still greater heat is developed, so that the star becomes white or even bluish-white in colour. But if the mass is small the gain of heat by contraction will be less, and may not be enough to make up for the natural cooling of the body by radiation into Space. So there is a turn of the tide before a white heat is reached, and the star begins to cool and grow redder. But in any case, whether the star be of great or small mass, the turning must come at some stage or other, and the changes of colour must be gone through in this reverse order. Meanwhile the contraction is continuing, though

less violently, so that the star, as it approaches the end of its career, becomes more and more dense, and when it has reached the red stage once more it has all the characteristics of a 'dwarf'.

When this theory of stellar evolution was first propounded it was believed that the red dwarf stage marked the visible end of a star's career. Since then, however, we have become aware of the existence of a type of star which was not previously recognized and which will not fit into the scheme of things just outlined. This type of star is even smaller and denser than the red dwarfs, but its surface brightness is much greater, and it is *white* in colour, like a comparatively young or middle-aged star. Such a star is known as a 'white dwarf', and, in order to understand how the occurrence of the type can be accounted for, we must first consider what is happening in the interior of a star during the period of its evolution.

When a star is young the atoms of which it is composed are very loosely packed. But when contraction occurs collisions between them become more frequent and violent. This raises the temperature of the mass and at the same time leads to the actual destruction of certain of the atoms, their substance being transformed into 'radiation', that is, into heat and light. Thus we see that in giving out heat a star is at the same time losing some of its mass, and the rate of loss increases with the rise of temperature. So the stars become gradually less massive as they grow older. At the same time, when the temperature has become very high in the interior of the star, the atoms themselves (which

are like little solar systems, with a central 'nucleus' and planet-like 'electrons' revolving round them) are broken down, so as to occupy a much smaller space than when they were less heated. With some kinds of matter this process seems to be delayed until the stars are very small and dense and the interior temperature very high. If this happens the surface of the star, still further reduced in area by the packing together of the broken atoms, is too small to radiate all the heat that is being generated, so its temperature is raised and it becomes white. This is the suggested explanation of the occurrence of white dwarfs, which represent a sort of dying effort at revival on the part of stars which would otherwise be near the end of their visible life as orange dwarfs.

A star takes much longer to grow old than it does to grow up. That is to say, it remains much longer in the dwarf than in the giant stage, and this is the reason why giant stars are relatively rare.

The actual range of the diameters and densities of the stars is enormous. Though it is impossible actually to see the disc of any star, we can, in the case of a few of the largest and nearest, measure its size with an instrument known as the 'interferometer'. The results agree remarkably closely with those deduced from theory alone, and show that a red giant is vastly bigger than our Sun, which, by the way, is a yellow dwarf. To take an example, the star Betelgeuse, in the 'shoulder' of Orion, is found to be over 250,000,000 miles in diameter; which means that if his centre were where our Sun is, his surface would be well out-

side the orbit of the Earth; and even larger stars than this are known. At the other end of the scale we have white dwarfs like the small companion of Sirius, the brightest star in our sky. This little body is only about three times the diameter of the Earth, or less than $\frac{1}{10,000}$ of that of Betelgeuse (see Fig. 4).

The densities of the stars vary over almost as wide a range. The matter in a red giant like Betelgeuse is so loosely packed that it would take hundreds of cubic feet of it to weigh as much as the air in a child's balloon, while the substance of a white dwarf, though still behaving like a gas, is so heavy for its bulk that a similar volume of it would weigh some hundreds of tons!

It is important to remember that the light which enters our telescopes and spectroscopes from the stars comes only from their surfaces, which are their coolest parts. The temperatures of millions of degrees, which produce the effects described above, are characteristic only of the interiors of the stars, and are calculated from the known laws which govern the behaviour of gases under various conditions. The spectroscope merely shows us what is happening in the relatively cool atmospheres surrounding the hot central parts of the stars. Here the range of temperature is much less than in the interior. Thus the surface temperature of a star just hot enough to give a dull red light is about 2500° C., while the whitest stars are at hardly more than 30,000° on their outsides—say about twelve times as hot. In the great heat of the interior the atoms are very much mixed together,

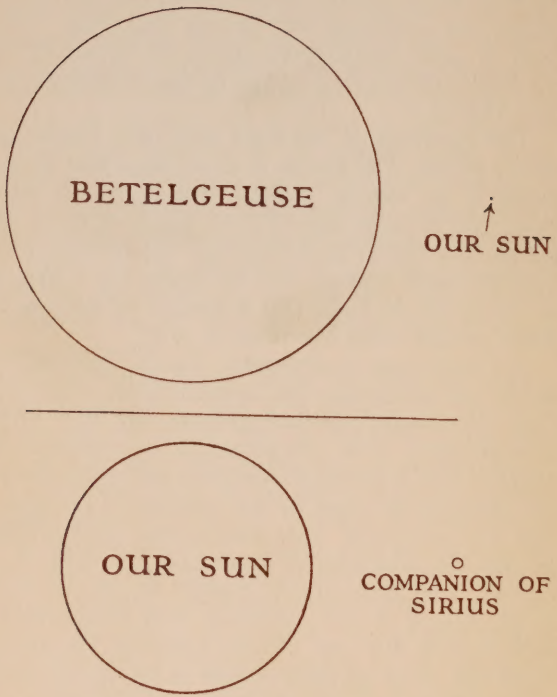


Fig. 4.—DIMENSIONS OF THE STARS

and, as we have seen, largely broken up. But on the surface they have a chance of taking on the normal structures that are typical of the various elements, and the cooler a star is the greater is the number and variety of the gases which can be separately identified in the spectroscope. In the case of the hottest stars only the simpler and lighter elements show themselves in the atmosphere, and they make themselves visible by the obstruction of light of definite colours in its passage from the hotter parts below. In the cooler, or yellower, stars the gases of the heavier elements, like the metals, appear; and, in the coolest of all, the atoms are even able to combine to form the more elaborate substances known as compounds.

In the early days of the spectroscope it was thought that these differences meant that the stars were not all composed of the same substance, and it was customary to refer to 'Hydrogen stars' or 'metallic stars'. But it is now believed that, broadly speaking, the stars are all made of the same materials, and that the various forms in which this matter appears to us in the stellar atmospheres are merely the result of differences of temperature. In fact, the stars show us that matter is essentially the same, and has the same properties, throughout the Universe. It is only the conditions that differ, and it is by studying the stars as vast crucibles that we can learn of the effects of these conditions in a way that would be impossible in our own laboratories.

CHAPTER VI

CHANGE AND MOTION IN THE HEAVENS

THE alterations which are supposed to occur in the character of a star during its life-history, as described in the last chapter, must occupy vast periods of time, running into millions of years. Such changes, taking place slowly and progressively throughout the centuries, are known as 'secular', from the Latin *saeculum*, meaning an age. They are far too slow in their operation to be detected in a human life-time.

But there are other changes of a much more rapid kind going on among the stars, and these can be readily observed in quite a short time. They are of a 'periodic' character, which means that they are repeated again and again, and are recognizable by the way in which they affect the amount of light received from the stars concerned.

Most of the stars which we see with the naked eye remain of practically the same brightness night after night and year after year. But it has been noticed for some centuries that two or three of them are variable in light, and the telescope has since brought to our knowledge some thousands of examples of the same thing among the fainter stars.

The brightness of a 'variable' can be measured by the eye with an instrument known as a 'photometer', or else it can be deduced from the size of its image on a photographic plate. Still more accurate measures can be made by noting the

effect of the light on certain delicate electrical instruments, though at present only the brighter stars can be dealt with satisfactorily in this way.

Whatever method is used, the varying magnitude of the star is plotted on a chart, as is done in the case of a sick person's temperature; and the tracing produced, called a 'light curve', shows a similar series of waves as the star waxes and wanes in light. In this way a great deal can be learnt as to the manner in which the changes are taking place, and it has been found possible to classify the variable stars according to the shapes of their light-curves, and, in certain cases, to deduce from them the true causes of the variability observed.

Briefly, it has been established that variable stars fall into two separate classes, one in which the changes are only apparent, and the other in which they are real. In the first case the variations of brightness are due to the mutual eclipses of two stars revolving round their common centre of gravity. The amount of light cut off in this way will clearly depend on whether the eclipse is total or partial, and also on the relative sizes and luminosities of the two bodies concerned. All these things can be deduced from the shape of the waves in the light-curve, which also shows us whether the two stars are near together or far apart. Even their very shapes can be inferred in the same way, and this is particularly remarkable when we remember that the bodies are so distant and close together that their combined light forms a mere point in the largest telescopes.

These mutual stellar eclipses occur with perfect

It will be evident that the apparent variability of such pairs of suns is, from our point of view, a mere accident, depending on the chance that the level of their paths is in or nearly in our line of view; and for this reason eclipsing variables are not exceedingly common. But when we come to the stars which undergo a real change of light, the element of chance no longer operates in this way, and we find, in fact, that the great majority of known variables can be placed in this class.

The changes which occur in the light of these stars are not so rigidly regular as in the case of the eclipsing variables, nor does the spectroscope suggest that more than one body is involved. They are also of a different colour, showing that they are not at the same stage of development. The stars which behave like Algol or Beta Lyrae are all near the zenith of their growth, being intensely hot and white. But the variables we are now considering are red and yellow giants at a much more youthful stage of their careers. The reddest ones vary very slowly, in periods between three or four months and over a year. For this reason they are generally referred to as the 'long-period' variables, and the amount of change shown in their light is greater than is seen in any other type. The variations are continuous, so that the light-curve consists of a series of more or less regular waves. The evidence of the spectroscope suggests that they are undergoing a sort of rhythmic pulsation, and that they are hottest and brightest at the time when they are most shrunken in figure.

The yellow variables are generally similar in the

manner of their variation, but their light-curves are more regular in shape and their periods are much shorter, ranging from about two months to a few hours in length. The change of brightness is also smaller. Here again the spectroscope indicates that a pulsation is at the root of the variability, but in this case the star is at its brightest when it is in its most swollen condition. One of the brightest variables of this type, and the first to be studied, is the star Delta Cephei, and for this reason the name 'Cepheid' has been given to the class as a whole.

It has been suggested that the three kinds of variable star just described are connected with one another in a continuous sequence. According to this idea certain stars develop a slow pulsation in their early youth, while they are red giants, and this pulsation increases in frequency as they pass through the hotter yellow stage. Finally, when they reach their white heat, they split into two separate bodies (on account of quickened rotation following their contraction in size) and appear, under suitable conditions, as eclipsing variables. But, though this may be an attractive theory, there are some difficulties connected with it, and it is not yet clear why these things should happen to some stars and not to others.

There is one characteristic of the Cepheids which is of exceptional interest and importance. It has been found that there is a close connection between their real brightness and the period in which their light varies. This means that we have only to glance at the light-curve of a Cepheid in

order to know how bright it really is, and this, taken in conjunction with its apparent lustre, gives us at once its distance from us. This supplies us with a new and powerful method of estimating distances far beyond the scope of the triangulation method, and its application will be referred to in the next chapter.

All the variables which I have mentioned up to now may be described as 'regular'—more or less—in their changes of light. But there are others which vary in what seems to be quite a capricious manner, blazing up or fading at erratic intervals. For these no really satisfactory explanation has yet been suggested; and the same applies to that very spectacular type of bodies known as Temporary Stars or *Novae* (*i.e.* New Stars). These appear to represent a sudden convulsion of explosive violence, taking place in an existing star, and causing it to increase in brightness many thousands of times in the space of two or three days. A much slower fading then sets in, and within a few years the star has returned to its original faintness. It has been suggested that we are here witnessing the result of a celestial collision of some sort, but most astronomers now think it more probable that a spontaneous explosion, originating in the star itself, is responsible.

The outlines of the constellations undergo no perceptible change from year to year, or even from one century to another, so far as the unaided eye is able to tell. Hence the expression 'fixed stars', to draw a distinction between these bodies and the wandering planets. But we have now come to

realize that, in spite of general appearances, there is no such thing as a fixed star. All the suns of Space are in constant motion, and it is only their great distances which render that motion so inconspicuous.

The movement of an individual star among its fellows is referred to as its 'proper motion', from the Latin *proprius*, meaning 'its own', in order to distinguish it from the apparent rotation of the whole star-sphere caused by the Earth's rotation. Even so, the expression is not quite exact, because at least a part of the observed motion of every star is not its own, but is an apparent effect due to the bodily motion of our Solar System through space.

This motion of the Sun and his planetary family was discovered at the end of the Eighteenth Century by Sir William Herschel, who noticed that, of the few stars then observed to be moving, those in one part of the sky seemed to be opening out from one another while those in the opposite quarter of the heavens were closing together. The same kind of thing may be seen if, when walking through a wood, we look at the trees in front of and behind us.

The point in the sky towards which the Sun is carrying us is not far from the bright star Vega, in the constellation of the Lyre, and we now know that the journey through Space is being accomplished at a speed of about twelve miles per second. The fact that this rapid motion makes so little difference, in hundreds of years, to the general appearance of the heavens, is one of the most

striking illustrations of the vast remoteness of the stars. Astronomers in years to come will find the Sun's movement very useful, for it will, in the course of time, provide a base-line of increasing length for the purpose of determining stellar distances.

In order to ascertain the real motion of any star we must do four things. First we must observe the amount and direction of its apparent movement against the background of the more distant stars. Secondly we must measure its distance, so that we can translate this apparent motion into actual miles per second. Thirdly we must find out, by means of the spectroscope, whether and how fast it is moving towards or away from us, in addition to the side-motion already ascertained. Finally we must make due allowance for the false effect produced by our own movement.

Having done all these things, we are in a position to say how fast and in what direction the body in question is really moving, and we have collected the necessary information in the case of a fair number of stars. However, it is obviously impossible to complete our knowledge beyond a certain distance in Space, for if a star is very far away we cannot easily detect its side-motion, nor are we able to measure its distance by the most direct and satisfactory methods. It is important, therefore, to bear in mind that what we have learnt about the motions of the stars only applies, strictly speaking, to our own particular portion of Space, and we cannot be certain that a similar state of things exists everywhere.

Briefly, it has been found that, while individual stars may and do move in all sorts of directions, there is a general tendency for them to be divided into two distinct groups, moving in opposite directions. Some idea of what is happening may be gathered by picturing a somewhat elongated frozen lake, on which a crowd of people are skating. Each person is free to move in any direction he pleases, and many will be seen crossing the lake diagonally from different points; but, on the whole, one would be able roughly to divide the skaters into those moving 'up' and those moving 'down' the lake. In such a case it would, of course, be the shape of the lake which would give rise to the general tendency observed, but it is not suggested that such an analogy holds in the case of the stars. I simply give it to illustrate the existence of *some* cause or other for the motions observed. What this cause actually is we have not yet discovered.

There is a curious relation between the supposed age of a star and the speed with which it moves. It has been found that, on the average, the young stars, or red giants, are moving through space more rapidly than the more mature white stars. But the slowing down seems then to stop, so that we find the dwarfs actually going faster again as they approach their red old age. No good explanation has been advanced to account for this very peculiar state of things.

Apart from the general tendency of the near stars to belong to one of two main 'streams', the motions of the individual suns are not in every case haphazard, even in appearance. It has been estab-

lished that there are, in certain parts of the sky, definite groups or families of stars whose members are all moving with a similar velocity in parallel lines; but the individual stars in some of the groups are, as we see them, so widely separated in the sky that their real connection with one another would never be suspected at a casual glance. In some cases the members are found in almost opposite quarters of the sky, which shows that we are actually passing through or very near to the group concerned.

The planets of the Solar System, as we have seen, move round their central Sun in curved paths; but this fact could scarcely be detected by watching one of them for a few minutes only. We must observe such a body for a much longer time before the shape of its orbit can be properly determined. The same thing applies to the motions of the stars. It is very probable, as we shall see later, that the paths which they follow are far from being straight lines, but we have not observed the motions long enough to be able to detect any curvature that may exist. But there are examples of stellar motion on a sufficiently small scale for us to be able to see such curvature in quite a short time. This is the case with the so-called 'double' or 'binary' stars, of which many thousands are now known to exist.

A binary star consists of a pair of Suns revolving round their common centre of gravity like two waltzing partners. Sometimes they are of the same mass, and both then trace out the same sized orbit. In other cases their masses will be found to be very

unequal, with the result that the smaller is forced to describe a much larger curve than the other, since the common centre of gravity will in that case be much nearer to the more massive body.

The periods in which the mutual revolutions are performed naturally vary according to the separation of the two stars. When they are very far apart, and therefore easily separated with a small telescope, the motion is so slow that a complete revolution may take several hundred years. In fact in many cases no movement has been so far detected with sufficient certainty to establish their mutual connection. But with the closer pairs there is no doubt of this sort, as the periods are often only a few years in length, and in many cases two or three complete revolutions have been actually observed. There comes a point, however, at which binary stars can no longer be observed as such, even in our most powerful telescopes, since their components are too close together to be seen as separate objects. But we know that much closer pairs actually exist, for the spectroscope reveals, in many apparently single stars, the existence of two bodies in mutual revolution. In such cases the periods are only a few days, or even hours, in length, and it might at first sight seem strange that there is so large a gap between these small orbits and those of the telescopic pairs, which take years to go through the same motions. But there is no reason to believe that such a gap really exists, as calculation shows that pairs with periods a few months long would be moving too slowly for their motions to be readily detected by the spectroscope, while

they would at the same time be too close together to be seen as double stars with the telescope.

It is now believed that there is no essential distinction between the eclipsing variables and the spectroscopic binaries, the only outward difference being due to the chance of their orbits being so inclined as to cause mutual eclipses of the components to dwellers in our part of Space.

It seems, therefore, that we can with some confidence arrange the binaries in a continuous sequence that will probably represent the natural course of their evolution, beginning with the eclipsing and spectroscopic pairs of short period, and ending with the widely separated stars which complete their revolutions in hundreds or thousands of years. This idea is supported by the fact that, while the spectroscopic binaries are all white, and therefore comparatively young stars, a large proportion of the wide pairs are yellow or even reddish in colour and are evidently of greater age.

To the astronomer the great importance of the binary stars lies in the information which they give us as to the masses of the stars. Newton's law of gravitation enables us to determine the combined mass of two bodies in revolution round their common centre of gravity by observing the size of the orbits which they describe and the speed with which they describe them. In the case of the eclipsing binaries this information is given at once by the to-and-fro motion of each, observed with the spectroscope, combined with the period between eclipses. For the telescopic pairs we must know the distance first, before we can ascertain the

scale of the orbits. Having found the combined mass by this means, we can calculate the mass of each individual by noting the relative speeds at which the two are moving. All we know of the masses of the stars in general has been based on observations of the binaries, which may therefore be regarded as the key to our knowledge of stellar physics.

CHAPTER VII

A BOUNDLESS UNIVERSE

In trying to find out the greatest possible amount about the stars, as individuals, we have, of necessity, confined our study to the nearer objects. We have, in fact, examined only a small sample of Space in the neighbourhood of the Sun. But we cannot be satisfied with this, and must go on to enquire how far this sample is typical, and how it fits in with and is related to the Universe as a whole.

The few thousand stars which we see with the naked eye, and many fainter ones as well, do not form the real background of the heavens. In reality they are only the members of what we call the 'local cluster', of which our Sun is one of the units. We see many such clusters in different parts of the sky, but they, like our own stellar group, are themselves merely units in a much greater system of stars, known as the Galaxy.

This great flattened structure is of such vast dimensions that no direct measures of its diameter are possible. Our difficulties are increased by the

fact that we are situated nearly in its plane, so that we cannot study its ground-plan. We are, as it were, on the deck of the ship, and are unable to get so good a view of its outline as we could from the mast-head. However, by making use of the Cepheids in the way already described, and by other indirect means, we have been able to obtain a rough idea of its size and shape.

It appears to be approximately circular in outline with a diameter of something like 200,000 light-years.[1] It consists of clouds or clusters of stars, and as these lie more or less on the same level the whole system is very much flattened, somewhat resembling a pancake in section. The greatest thickness is probably not more than 10,000 light-years, or $\frac{1}{20}$ of its diameter. Our local cluster appears to be situated some way from the centre, perhaps nearly half-way towards the edge. As the system is so much flattened, we naturally see many more stars in the direction of its plane than we do in other parts of the sky. The more distant of these stars are too faint to be seen separately with the naked eye, but their combined light is visible to us in the form of a feebly luminous band. This is the so-called Milky Way, which seems to encircle the entire sky like a gigantic belt.

When we attempt to determine the true nature and extent of the Galactic system we are faced with much greater difficulties than those with which we have to contend in our study of the local cluster. Most of these difficulties are caused by the much

[1] A light-year is the distance light travels in one year, at 186,000 miles per second, or nearly six million million miles.

greater distances involved, one result of which is that we cannot even make a direct count of all the stars contained in the system. This is not because our telescopes will not reach out sufficiently far into Space, but rather because, as we approach the confines of the Galaxy, only the biggest and brightest stars are visible; whereas we have seen, from a study of the local cluster, that the smaller and fainter stars are there in the majority, as they probably are in most parts of Space.

There is, however, an indirect method whereby we can arrive at an approximate result. It has been discovered within quite recent years that the whole Galaxy is in rotation about its central parts under the influence of the gravitation of the whole system. Now we have seen how, by observing the rate of motion of a satellite, or of the companion of a star, we can determine the combined mass of the bodies concerned. An attempt has been made to measure the speed with which the stars in the vicinity of our Sun are travelling round the Galactic centre, and it appears that the velocity is about 200 miles per second. This fact, combined with the most probable radius of the vast orbit, shows that the mass of the whole system is something like 100,000 million times that of the Sun. Remembering that the masses of the stars in general are very similar, we are led to the conclusion that the total number of suns in the Galaxy is also about 100,000 millions. This result cannot be regarded as certain, since it is based on quantities which have not yet been accurately measured. But it is fairly probable that the estimate is not an

excessive one, though the figure indicated is, as was to be expected, much greater than that of the total number of stars accessible to our present telescopes, which amounts to about 2000 millions.

Another difficulty due to the distances of the Galactic stars is that they appear too faint to allow us to make a close study of their spectra, and we have already seen how much information can be obtained where this is possible. We can, however, obtain a very fair idea by an examination of the colour alone, as this is known to be closely related to the type of spectrum exhibited by each star. The result of such studies is to suggest that there is no essential difference between the character of the distant stars and that of the members of our local cluster. Reliance upon this supposed fact has helped us a great deal in the face of the next difficulty, which is that the 186,000,000-mile base-line of our Earth's orbit is far too short to enable us to measure distances which run into tens of thousands of light-years. If only we could be certain of the distance of a star from its appearance alone, without having to depend on its annual apparent shift, the difficulty would be solved. We believe that this is really the case with the Cepheids, as already explained; but where these are not found there is the possibility of using other types of star, though perhaps with rather less accurate results. The red stars are, as shown in an earlier chapter, of widely different sizes and brightness. But this is not so with the white stars, which, though not exactly alike, are much more nearly so than the highly coloured suns. In fact, we know the average

real brightness of the white stars with a fair degree of accuracy. We have therefore only to measure the average *apparent* brightness of the white stars in one of the star-clouds of the Galaxy in order to ascertain the real distance of that part of the system.

In this method of estimating distance by apparent brightness there is the possibility of a serious source of error. The theory assumes that the space between us and the stars is completely empty, containing nothing which could dim the light on its passage towards us. That this is really so is far from certain. We do, in fact, actually know of the existence of large clouds of dark matter, probably dust and gas, scattered throughout the Galaxy. But such clouds generally appear as pretty definite streaks or patches, fairly blotting out all that lies behind them; and it has generally been assumed that, where they are not readily recognized, there is no absorption of the light from the stars. Lately, however, some astronomers have begun to entertain serious doubts on this question, and, if these doubts are verified, it will mean that we must revise our estimates of the size of the Galactic system. Any such revision must be in the direction of a reduction of the figure of 200,000 light-years at present adopted, because the effect of a cosmic fog would be to make the stars appear fainter, and therefore more distant, than they really are. Future research will show how far, if at all, we have to reduce the estimate, but it seems unlikely that any very drastic change will be required, and we can safely continue to regard the Galactic system as

a structure some scores of thousands of light-years in diameter.

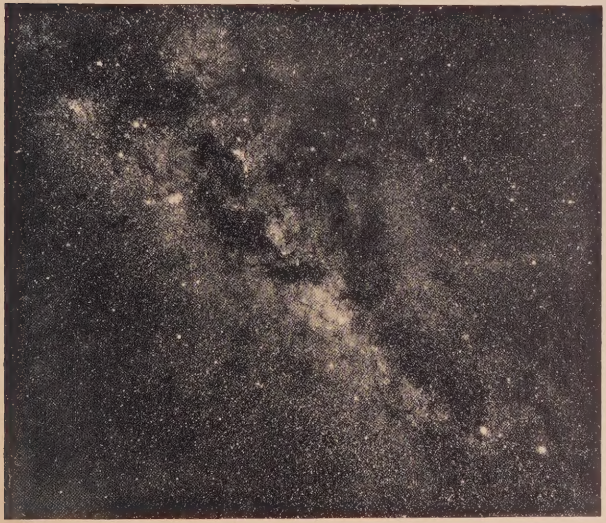
The clouds and clusters of stars which go to make up the Milky Way are very large and of rather irregular shapes, with considerable spaces between the members of each. But, lying on each side of the plane of the disc-like system, and evidently connected with it, are a limited number of star-groups of quite a different kind. These are the 'globular' clusters, and, as their name implies, they are of an approximately regular spherical outline. In them the stars, to the number of some tens or even hundreds of thousands, are apparently and actually more closely packed together than in the Milky Way groups, and each cluster appears in the telescope as a blazing ball of suns.

We see, therefore, that our great star-system consists of an enormous disc or wheel-like structure, composed of clouds of loosely scattered stars, together with an attached group of much smaller and more compact stellar families (see Fig. 5). We are naturally led to ask whether this vast assemblage of bodies represents the whole Universe, or whether it is only a unit in the Cosmos, even as our Sun is but a unit in a star-cluster, and the cluster itself a unit in the Galaxy.

Supposing that, out in the depths of Space, beyond the boundaries of our own stellar system, there were other Milky Ways, what would they look like to us? Remembering the naked-eye appearance of the Galactic star-clouds, we should naturally expect such external systems to appear as dim patches of misty light, supposing that their

A SPIRAL NEBULA

SPIRAL SEEN EDGEWISE



PART OF THE MILKY WAY

constituent suns were too distant to be separately visible in our telescopes. Now such misty patches have actually been observed in great numbers, in various parts of the sky, though only two or three are visible to the naked eye.

Objects of this kind are appropriately called 'nebulae' (*i.e.* little clouds), and their exact nature

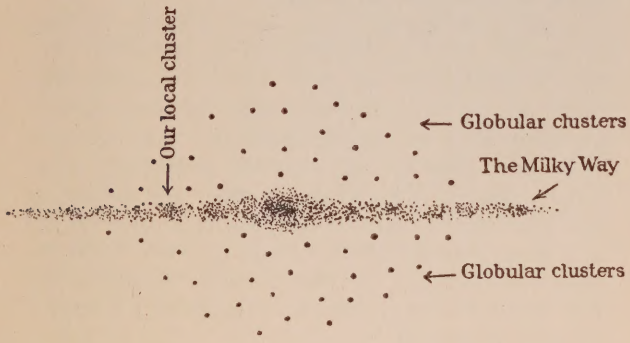


FIG. 5.—OUR STAR SYSTEM: AN EDGEWISE VIEW

was a puzzle to telescopic observers until quite recent times. Some astronomers regarded them as masses of dust and gas, destined each to condense into the form of a solar system like ours; while others, like Sir William Herschel, hazarded the guess that some at least were large collections of stars reduced to an apparent mistiness by distance. But until it was possible to find out what their distances actually were and of what substance they were composed, no progress could be made. All that could be established by the eye alone was that

there were certain differences of colour and shape among the nebulae. Some were bluish or greenish in tint, and these were in some cases globular and in others irregular in outline. But the great majority were white and of a rather regular shape, being either circular or more or less elliptical; and a few of the larger ones could just be seen to have a spiral or whirlpool structure.

It remained for the spectroscope and the camera to supply a complete solution of the problem. The former instrument showed that the nebulae are really of two very distinct kinds. The bluish and greenish ones are purely gaseous, and we now know that they are all included within our own stellar system. The globular ones all contain a small hot star at their centres, and it is conjectured that they may be shells of gas thrown violently outwards from this nucleus, possibly during some such explosion as appears to be associated with the outburst of a nova.

The irregular gaseous nebulae are generally found in association with giant stars, and it is believed that they represent the matter which is being gradually and constantly radiated away into Space by these bodies in the course of their development. In fact we look upon them as the waste-products of evolution rather than as material which is about to condense into new bodies. The dark obscuring clouds already referred to are often found near to and mixed up with this luminous nebulosity, of which they may perhaps be regarded as a later and cooler stage.

The white nebulae, on the other hand, give no

evidence of the presence of gas when examined with the spectroscope. On the contrary, their light is of just the sort that would be emitted by a collection of stars. The camera further shows that they are mostly flattened, lens-shaped discs, very similar in shape to our Galactic system, and that very large numbers of them are of spiral structure. Until quite recently, however, even the best photographs showed them as misty objects rather than as collections of definite star-points. But during the past few years our largest telescopes have finally removed all doubt by showing the actual stars in certain of the nearest spiral nebulae. Among these stars have been found a number of Cepheids, and this has made it possible to estimate the distances of these nearer spirals. The result has been to show that Herschel's guess was correct, and that the white nebulae are, in truth, stellar systems far removed from our Galaxy, and to all appearance very similar to it in structure, if not in size.

One of the nearest of the spiral nebulae appears in the direction of the constellation Andromeda, and is faintly visible to the naked eye. It proves to be at a distance of somewhat less than a million light-years, and is about 50,000 light-years in diameter. This would make it a good deal smaller than our own system, and it has been suggested that the latter should rather be regarded as a 'super-Galaxy', containing as much material as would go to the making of a number of objects like the Andromeda nebula. But, in view of the possible exaggeration of its dimensions, this view may be rather premature.

It is only in the nearer spirals that the actual stars can be reached by our present telescopes, so that we cannot use the Cepheid method for finding the distances of those more remote. It has been found, however, that those nebulae which are near enough for this method to be applied are of much the same real size, and, by making the rather bold assumption that such similarity is the general rule, we have ventured to estimate the distance of the remaining spirals from measures of their apparent size alone. By this method nebulae have been found whose distance is inferred to be nearly 150,000,000 light-years!

These external galaxies are by no means evenly distributed over the visible surface of the heavens. It was noticed long ago that they seemed to avoid the regions occupied by the Milky Way, but this is now believed to be no more than an apparent effect, due to the interposition of the galactic clouds of absorbing matter already mentioned. However, even at a distance from the plane of the Milky Way, their distribution in Space does not appear to be quite uniform, there being a marked tendency for them to collect into groups or clusters. Whether this grouping tendency is always real is not yet quite certain, for some of the parts of the sky apparently rich in nebulae may conceivably represent regions of greater transparency, in which we see to a greater distance than elsewhere. In other words the obscuring clouds of matter may not be confined to the plane of the Galaxy, though they can only easily be detected there on account of the brighter background which shows them up.

The spirals are by no means all alike in appearance, and we believe that in the differences observed we can detect the stages in a regular cycle of evolution, as we did in the case of the individual stars. In the nebulae which are considered to be the youngest there is little if any trace of spiral structure, and their substance, which shows no sign of condensation into separate stars, is much concentrated towards the centre of the mass. In a later stage star-like condensations begin to show themselves in the diffuse matter, and these are arranged in spiral streams, starting from the centre. As more and more stars are formed, the central mass is denuded of its material and becomes much less conspicuous. Finally, nearly all the matter is converted into clouds of stars, and the ever-widening spiral arms begin to lose their regular shape.

This appears to be the case, for instance, with the great spiral in the constellation Triangulum, which is the nearest of all the island systems, and also perhaps with our own Galaxy. In both cases there appears to be relatively less matter left at the centre, and what there is in that part of our system is probably for ever hidden from our view by obscuring clouds.

Most of the nebulae are too far-distant for us to be able to recognize anything parallel to our subordinate system of globular clusters; but in the case of the great Andromeda spiral some objects very like them can just be detected, and the way in which they are distributed about the nebula makes it still more likely that they are really what they are suspected to be.

Another point of similarity between our Galaxy and the spirals is that some of the latter are accompanied by smaller companion nebulae, which have, perhaps, been thrown off the parent body in the course of its development. Now we have some reason to believe that two semi-spiral masses of galactic type, called the Magellanic Clouds, stand in the same relation to our own system as the companion nebulae do to the distant spirals. These objects, which are a good deal smaller than the Galaxy, are not far from the direction of the South celestial pole, and cannot therefore be seen in Northern latitudes. They are clearly visible to the naked eye, and, when examined with the telescope, appear very similar to portions of the Milky Way seen at a great distance.

We are generally accustomed to associate great size with sluggishness of movement, but it is a very remarkable fact that the spiral nebulae, which are, so far as we know, the largest units in the Cosmos, appear to be moving with greater velocities than any of the smaller collections of matter which we have studied. If we can rely upon the evidence of the spectroscope it would seem that these external systems are all spreading apart from one another at the rate of several hundred miles per second. It does not appear that there is any definite centre from which the scattering is taking place, so that we cannot quite compare the nebulae to the fragments of an exploding shell.

A better analogy is the expansion of a rubber balloon. Imagine such an object to be dotted all over with small ink-spots, close together and at

about the same distance apart. Now if the balloon is gradually inflated the spots will move away from one another evenly and simultaneously all over the surface. The point is that if any number of spots are selected at random, each will seem to be the centre of a similar expansion. Moreover, the speed at which its neighbours are receding from it will depend upon their distance. Suppose that the balloon is blown up at such a rate that the nearest spot increases its distance by one tenth of an inch in each minute. Then, as the distance of each pair of spots is increasing at the same rate, it follows that the second one will have moved a fifth of an inch from the adopted centre in the same period of time, while the tenth spot will have moved a whole inch.

We find the same sort of thing happening in the Universe. If we select any star system, our own for convenience, as a centre, we find that all the other systems appear to be receding from it, and that the velocity, *reckoned from this centre*, increases with the distance of the nebula concerned.

This apparent expansion of the Universe presents one of the most puzzling problems of modern Astronomy. It is not so much the *fact* of the expansion that constitutes the difficulty, for some mathematicians consider that this is to be expected on dynamical grounds; but it is rather the speed at which the expansion seems to be taking place. If the nebulae have always been moving apart with their present velocity they can only have existed as separate objects for a definite and limited time, the duration of which can be easily calculated. It

turns out that this period is far shorter than we at present believe necessary for the growth and development of the stars as we know them; so that we must conclude either that the nebulae were not always moving so fast, or that the velocities which they at present seem to have are wholly or partly unreal, being due to some unknown effect on their spectra.

The contemplation of the Universe in all its vastness has naturally taught us to regard the Earth as, cosmically speaking, a very unimportant body. As to the problem of its origin, it cannot be said that Astronomy has, as yet, any direct solution to offer; for we have never seen in operation in the heavens any process which would seem likely to result in the birth of a planetary system like our own. It has been suggested that such a process might be induced by the accident of one star passing very close to another and pulling from it, by tidal action, a streamer of matter which would later condense into planets. So far as we can calculate, such an accident would be exceedingly rare, as the average spaces between the stars are so great. Habitable globes may therefore be not so common in the Universe as was once vaguely believed, and this thought may help to restore some of that self-respect which we must almost inevitably lose in the face of what is inconceivably vast and awe-inspiring.

THE END

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